UNO and Very Long Baseline Neutrino Oscillation Experiment

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UCLA, California

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_ UNO

UNO

Detector (Water Cherenkov)

Total mass: 650 ktons

Fiducial volume:

440 ktons for proton decays

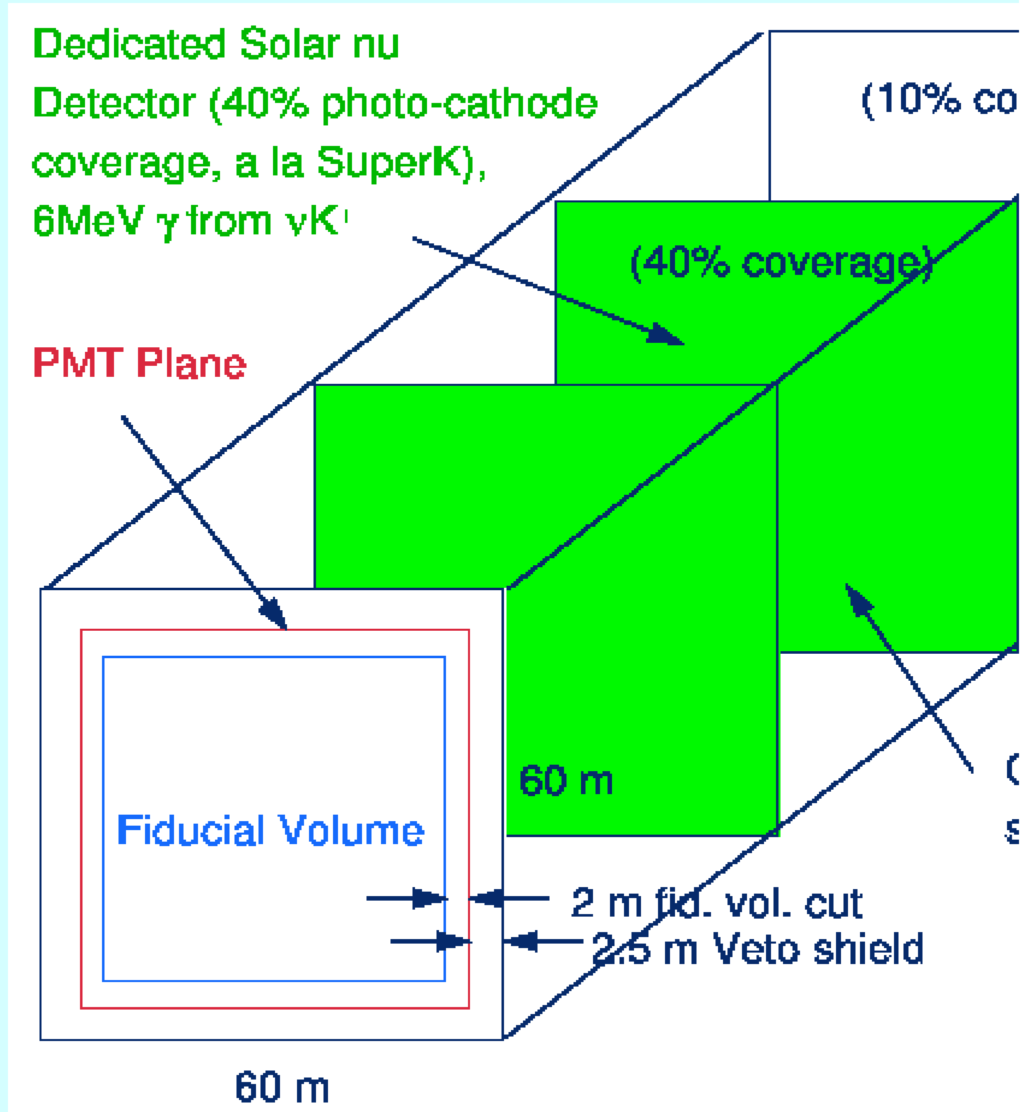
for solar ν

580 ktons for Supernova

Total size : 60x60x180 m^3

Photocathode coverage:

1/3 40%, 2/3 10%



History

- Proposed in 1999 at NNN99

-Whitepaper , July 2002 presented at Snowmass, signed by
23 institutions, 49 members: proto-collaborators
(22 institutions, 32 members: interest group)

-UNO Narrative for HEPAP 2003 report

-August, 2003: Proto-collaboration to collaboration

-April 2004: The collaboration made of
40 institutions, 94 members, and 7 countries (has grown since 2002)

-First EOI/R&D proposal 2005

Visit UNO website at http://nngroup.physics.sunysb.edu/uno/

UNO

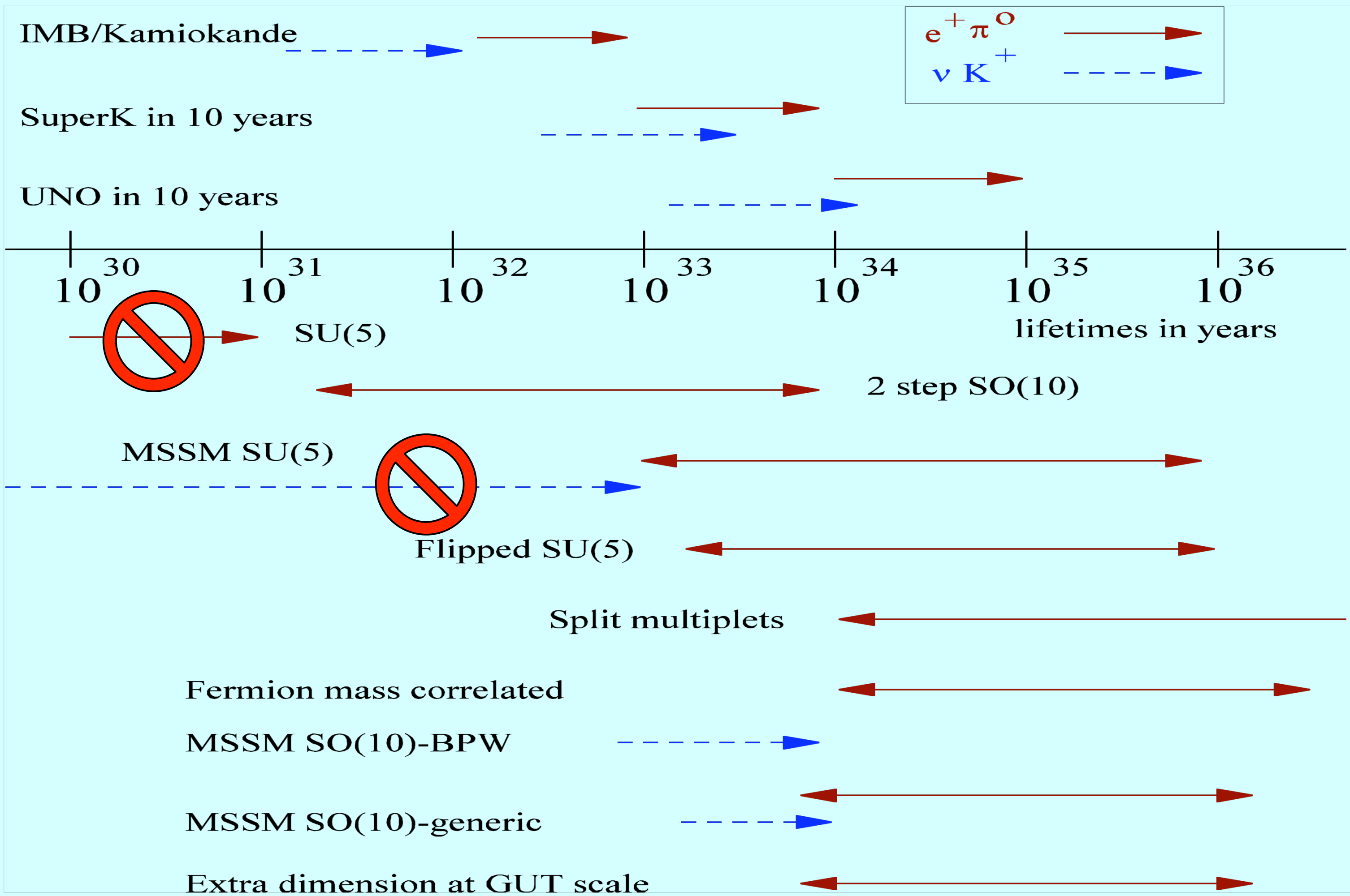
Physics Goals

- Nucleon decays
- Atmospheric neutrinos
- Supernova neutrinos
- Solar neutrinos
- Relic supernova neutrinos
- Very long baseline neutrino oscillation
- Others

UNO

Proton Decays

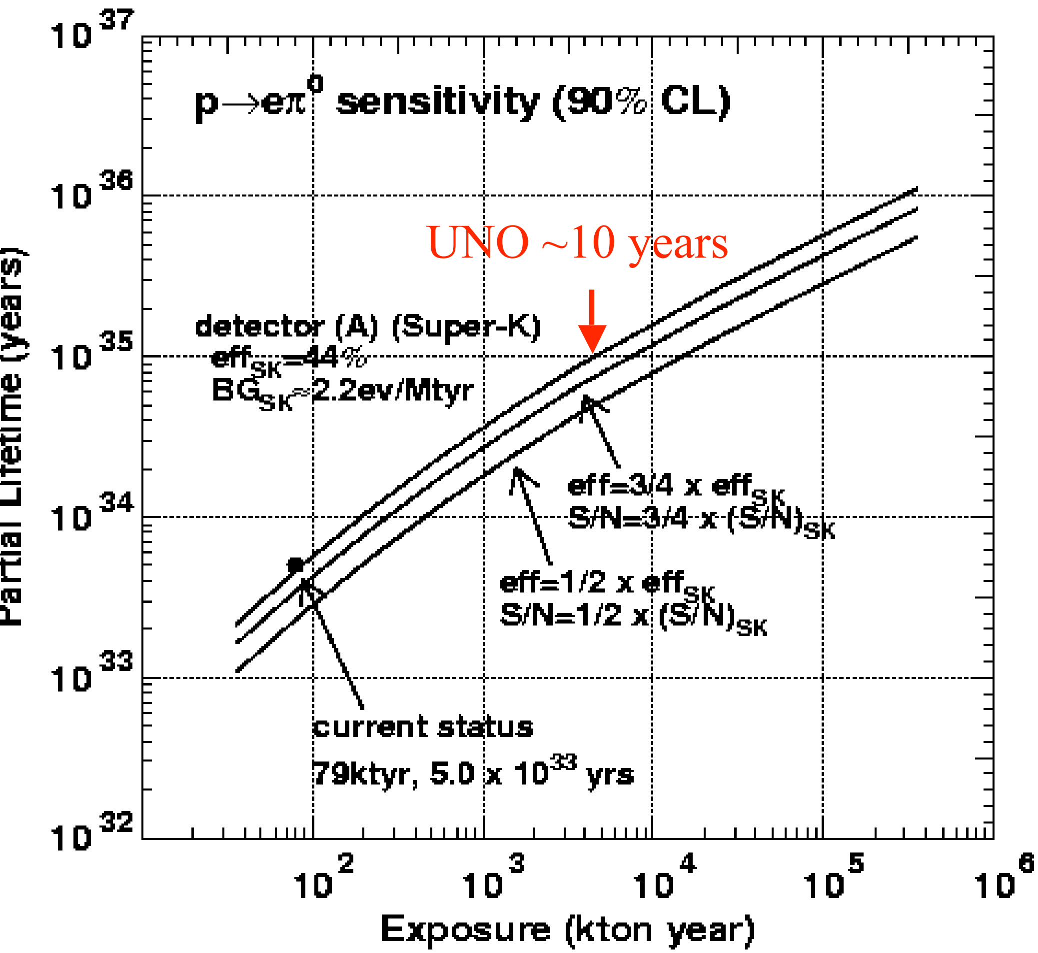
Proton decay rate limits/predictions

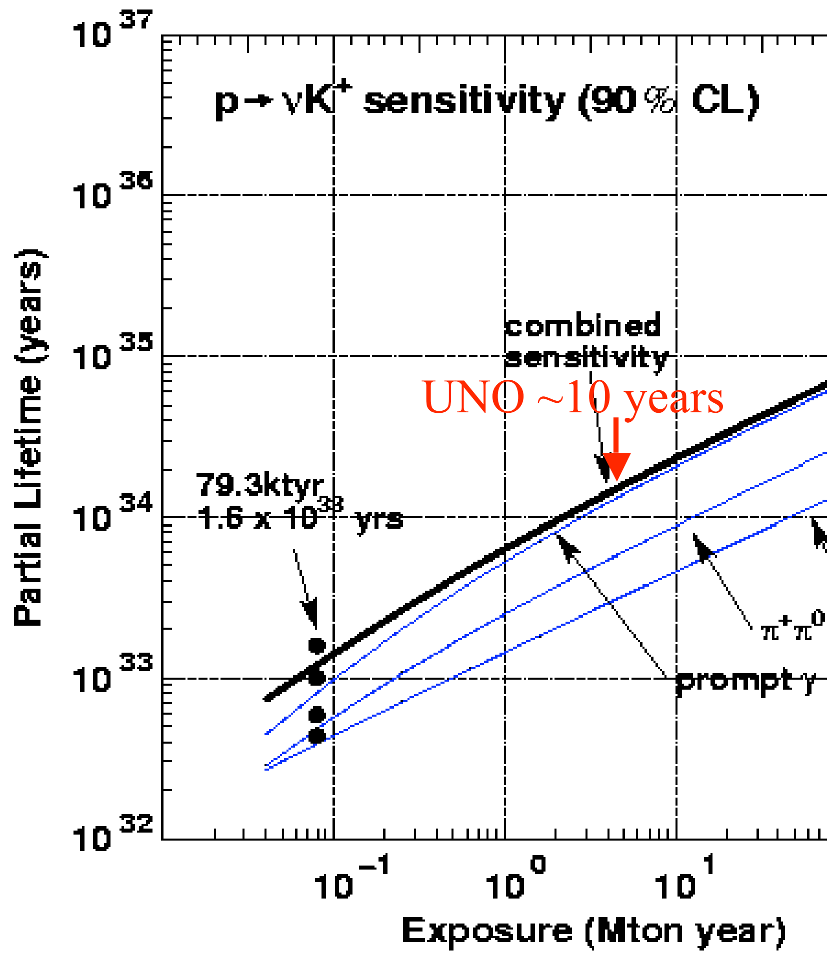


UNO

Proton Decays

Proton decay search sensitivities with SK efficiency and background level

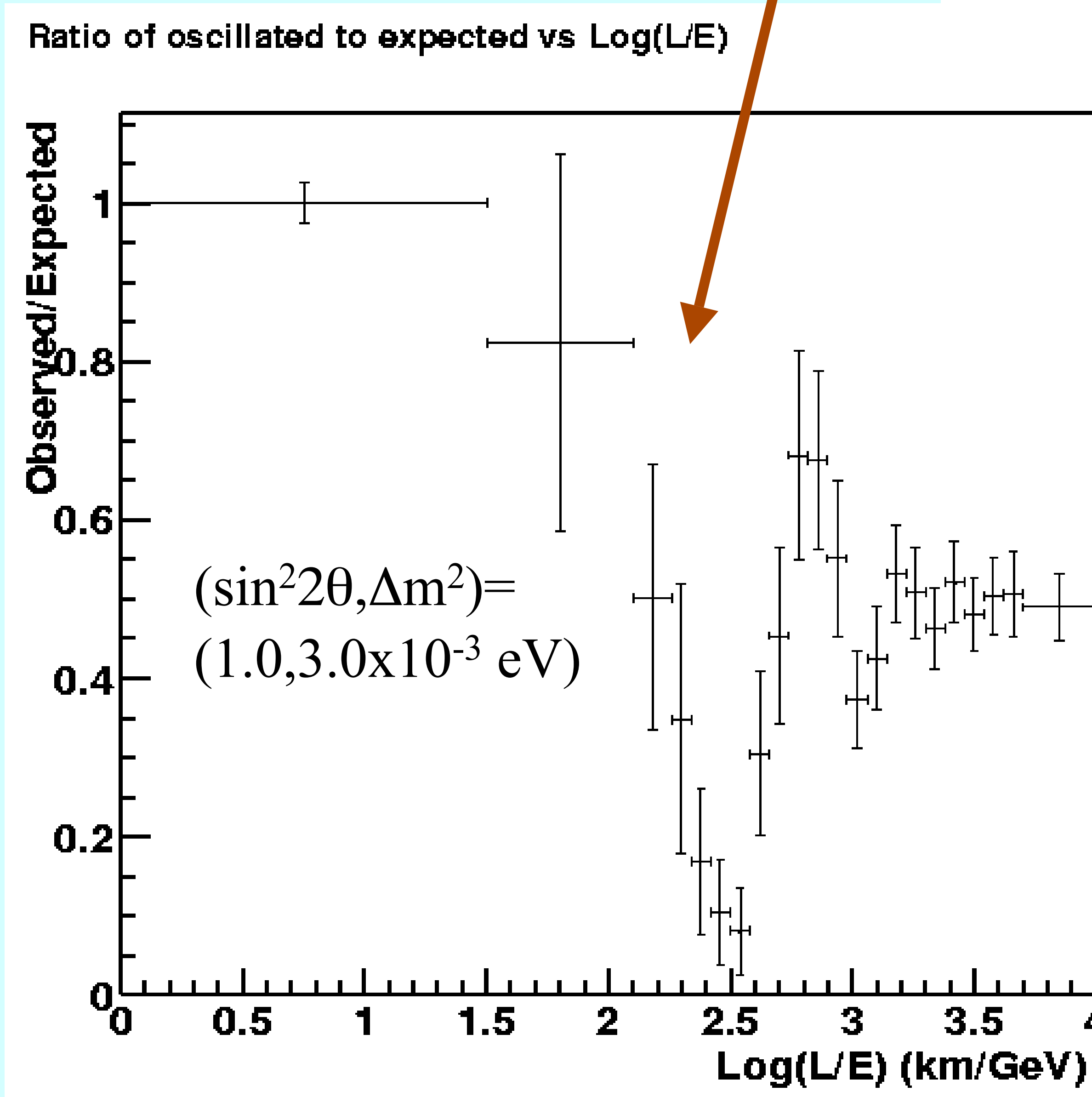




Atmospheric Neutrinos

L /E distribution to see oscillatory behavior

- UNO is much bigger than SK 20 x SK fiducial volume
- UNO has much longer lever arm than SK, i.e., better efficiency to detect high energy muons than SK
  SK up to ~7 GeV
  UNO up to ~36 GeV



UNO

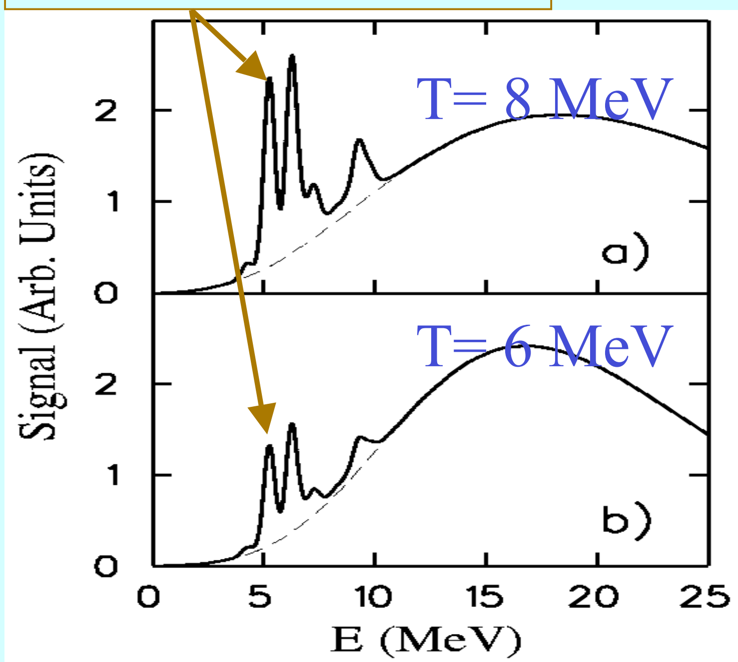
Supernova Neutrinos

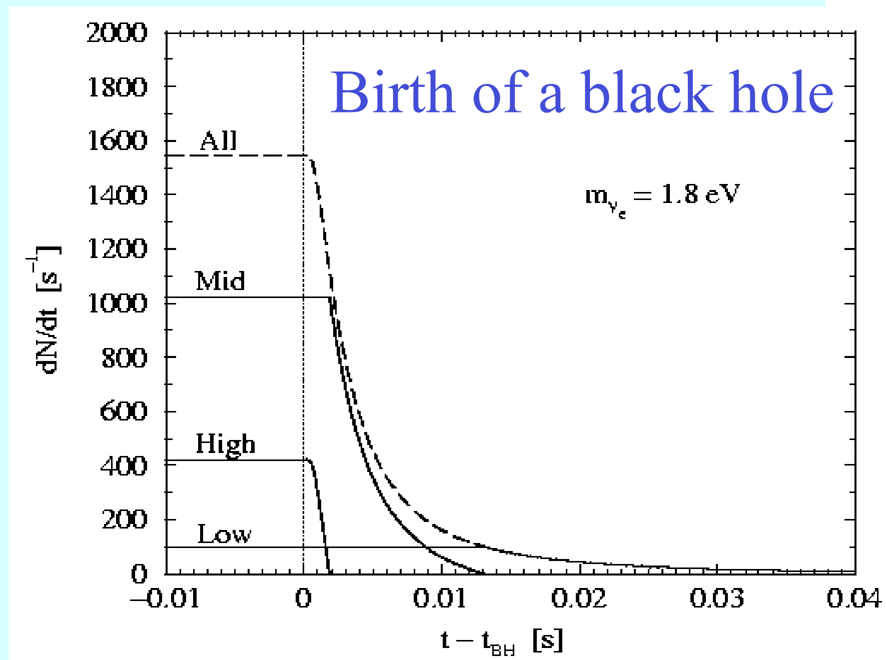
-For a SN at 10 kpc, UNO would detect 130,000 inverse beta decay events, 4,500 elastic scattering events, 4,500 neutral current events in the central region.

- High statistics might lead to our first observation of the birth of a black hole
- UNO is big enough to observe a supernova explosion even in Andromeda

Neutral current events

$\nu_x + {}^{16}O \rightarrow \nu_x + \gamma + X$ where $X = {}^{15}O, {}^{15}N, \ldots$





Very long baseline neutrino oscillation

VLBNO

Setting the stage

- **UNO, ~ a half megaton F.V. water Cherenkov detector**
- **BNL very long baseline neutrino beam**

- **VLB neutrino oscillation experiment**

See, for example, PRD68 (2003) 12002 for physics argument

How do we find the signal for $\nu_\mu \rightarrow \nu_e$?

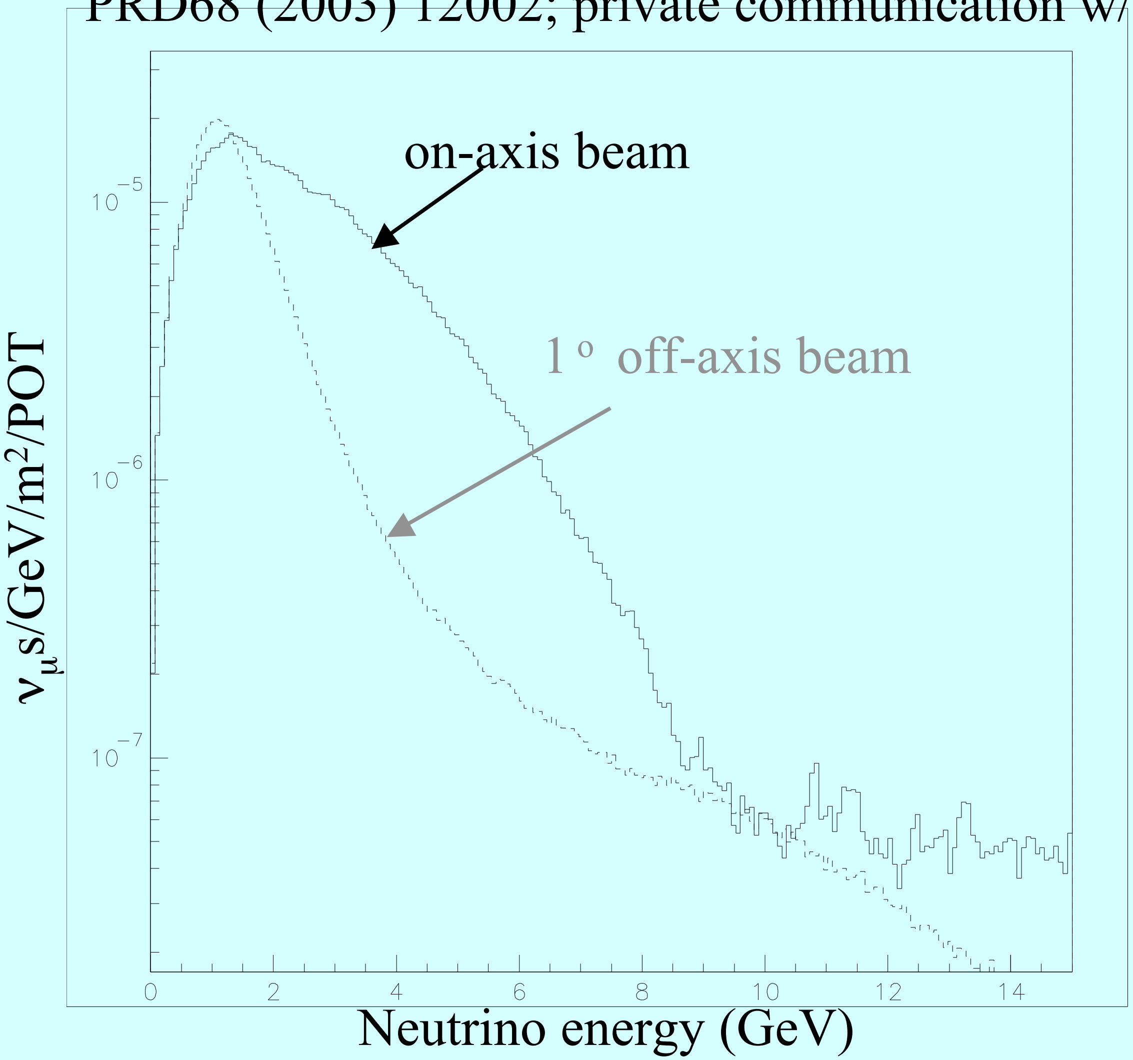
- **$\nu_\mu \rightarrow \nu_e$ and ν_e +N-> e + invisible N' + (invisible nπs,n>=0)**
- **Look for single electron events**
- **Major background**

  $\gamma\ (\gamma)$

  - $\nu_{\mu,\tau,e}$ + N -> $\nu_{\mu,\tau,e}$ + N' + π^0 + (invisible nπs,n>=0)
  - ν_e contamination in beam (typically 0.7%)

- Spectra of on- and off-axis BNL Superbeams

PRD68 (2003) 12002; private communication w/ M.Diwan



How is analysis done ?

- **Use of SK atmospheric neutrino MC**
  - Standard SK analysis package + special π^0 finder
  - Flatten SK atm. ν spectra and reweight with BNL beam spectra
  - Normalize with QE events: 12,000 events for ν_μ , 84 events for beam ν_e for 0.5 Mt F.V. with 5 years of running, 2,540 km baseline

    distance from BNL to Homestake
  - Reweight with oscillation probabilities for ν_μ and for ν_e
- **Oscillation parameters used:**
  - **Δm^2_{21} =7.3 x 10^{-5} eV^2, Δm^2_{31}=2.5 x 10^{-3}eV^2**
  - **$\sin^2 2\theta_{ij}$(12,23,13)=0.86/1.0/0.04, δ_{CP}=+45,+135,-45,-135^o**

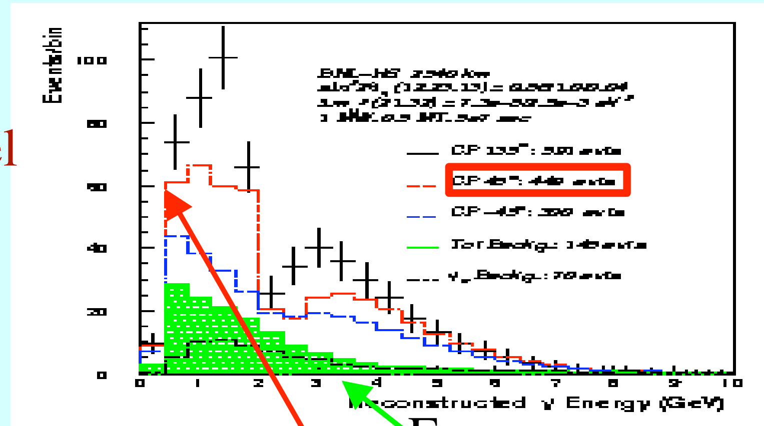
Probability tables from Brett Viren of BNL

First comparison with BNL report

ν_e QE for signal, all ν_μ , ν_e , ν_τ NC $1\pi^0$ for bkg

BNL report

Based on 4-vector level MC



E_{rec}

CP+45°

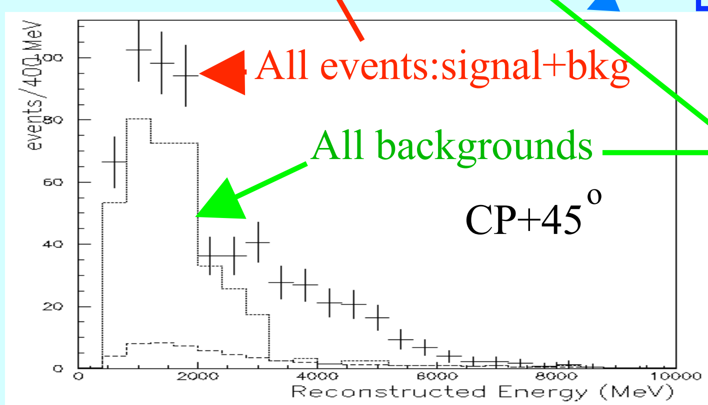
Signal 303 events

All bkgs 146
(76 from π^0)
(70 from ν_e)

Compare .... with +

My first study with full SK simulation

Using traditional SK variables + π^0 mass; similar cuts to BNL cuts



Signal 242 events

All bkgs 380
(324 from π^0)
(56 from ν_e)

E_{rec}

Need improvement!

Selection criteria to improve

- Initial cuts: Traditional SK cuts only
  - One and only one electron like ring with energy and reconstructed neutrino energy more than 100 MeV without any decay electron

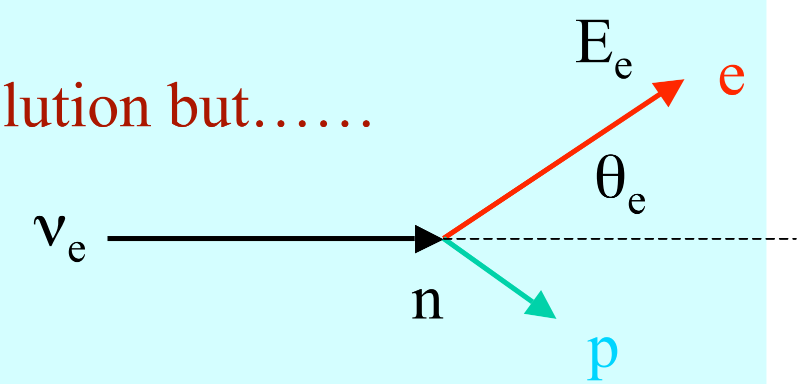
To reduce events with invisible charged pions

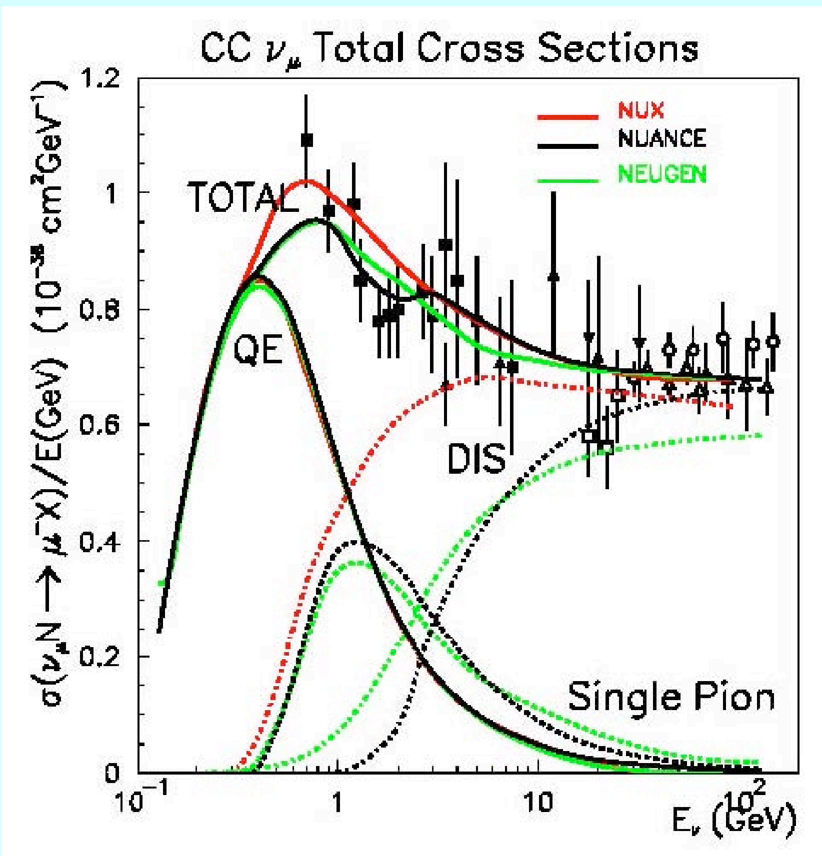
- Likelihood analysis using the following eight variables: With π^0 finder
  - π^0 mass, energy fraction, costh, π^0-likelihood , e-likelihood
  - $\Delta\pi^0$-likelihood, total charge/electron energy, Cherenkov angle

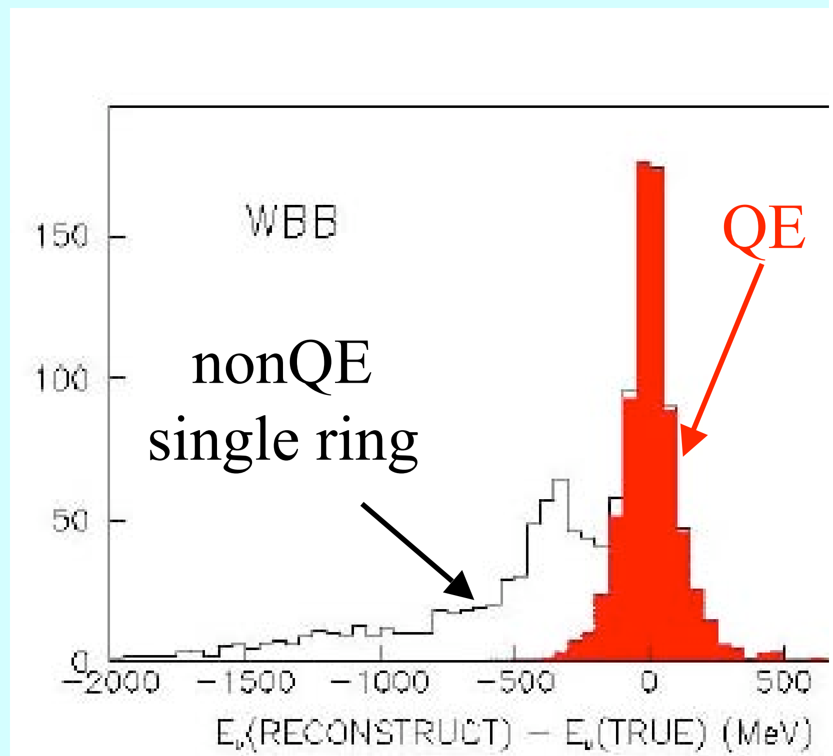
- What is sources of the signal?
  - **Neutrino energy reconstruction**

QE events give the best energy resolution but……

$$E_\nu^{rec} = \frac{m_N E_e}{m_N - (1-\cos\theta_e)E_e}$$



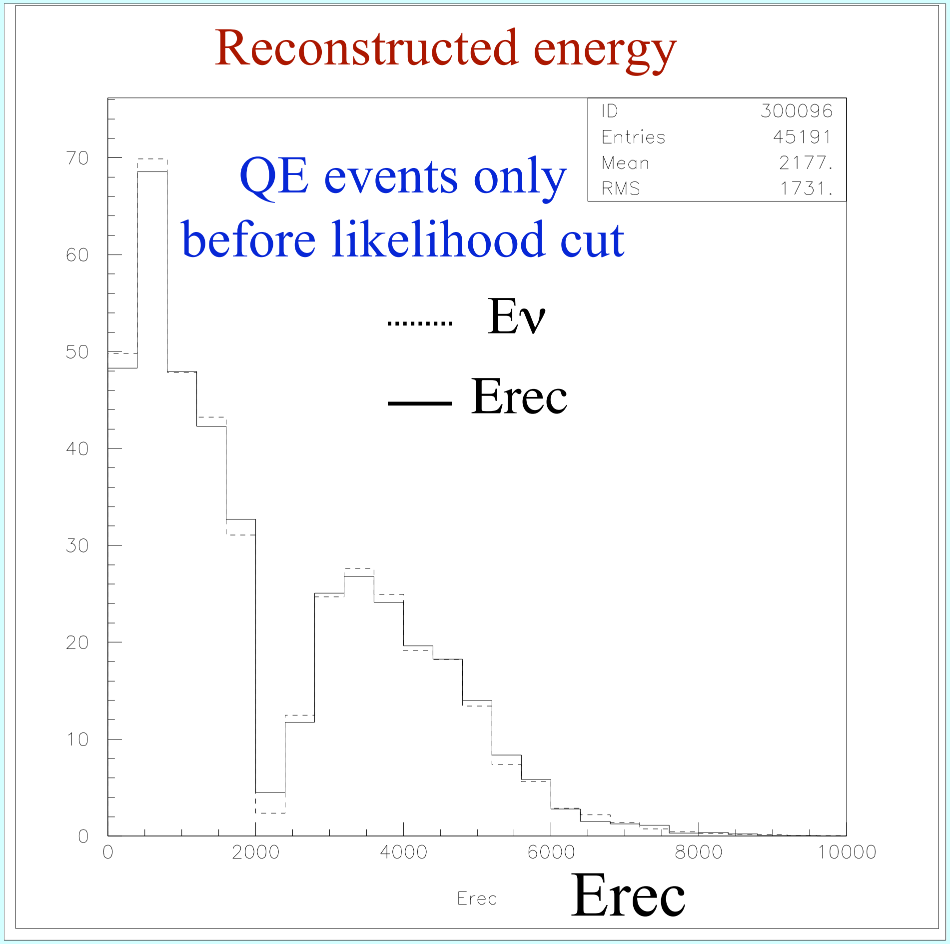


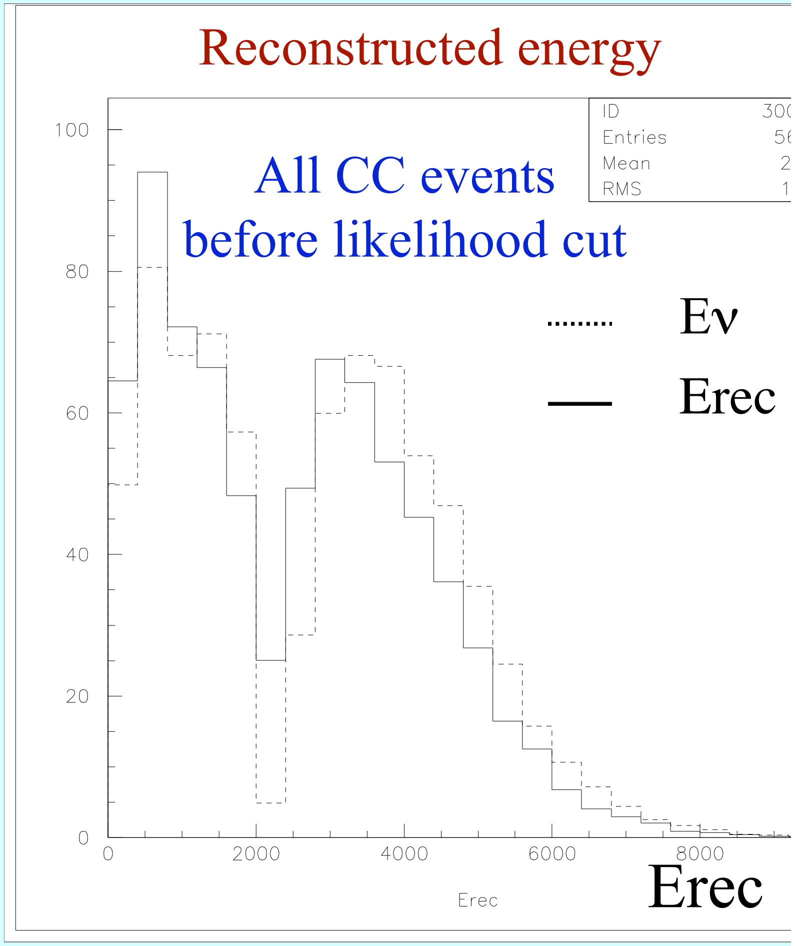


VLBNO

- What are sources of the signal? Single e-like events after initial cut

- **What are sources of the signal and of the background?**





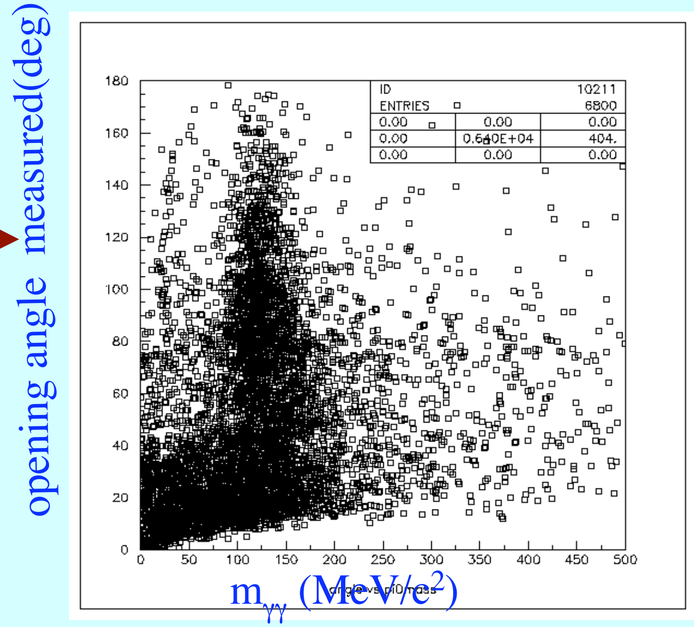
All CC events that survive the initial cuts are signals

_ π^0 Finder

π^0 finder

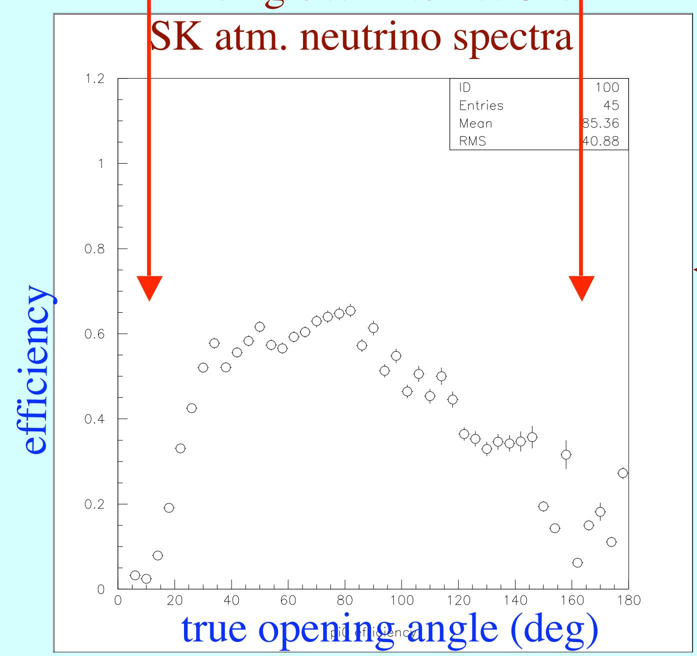
- π^0 finder Always finds an extra ring in a single ring event
  - **π^0 detection efficiency with standard SK software**
  - **measured opening angle vs. π^0 mass with π^0 finder**

Single e-like events from single π^0 int.



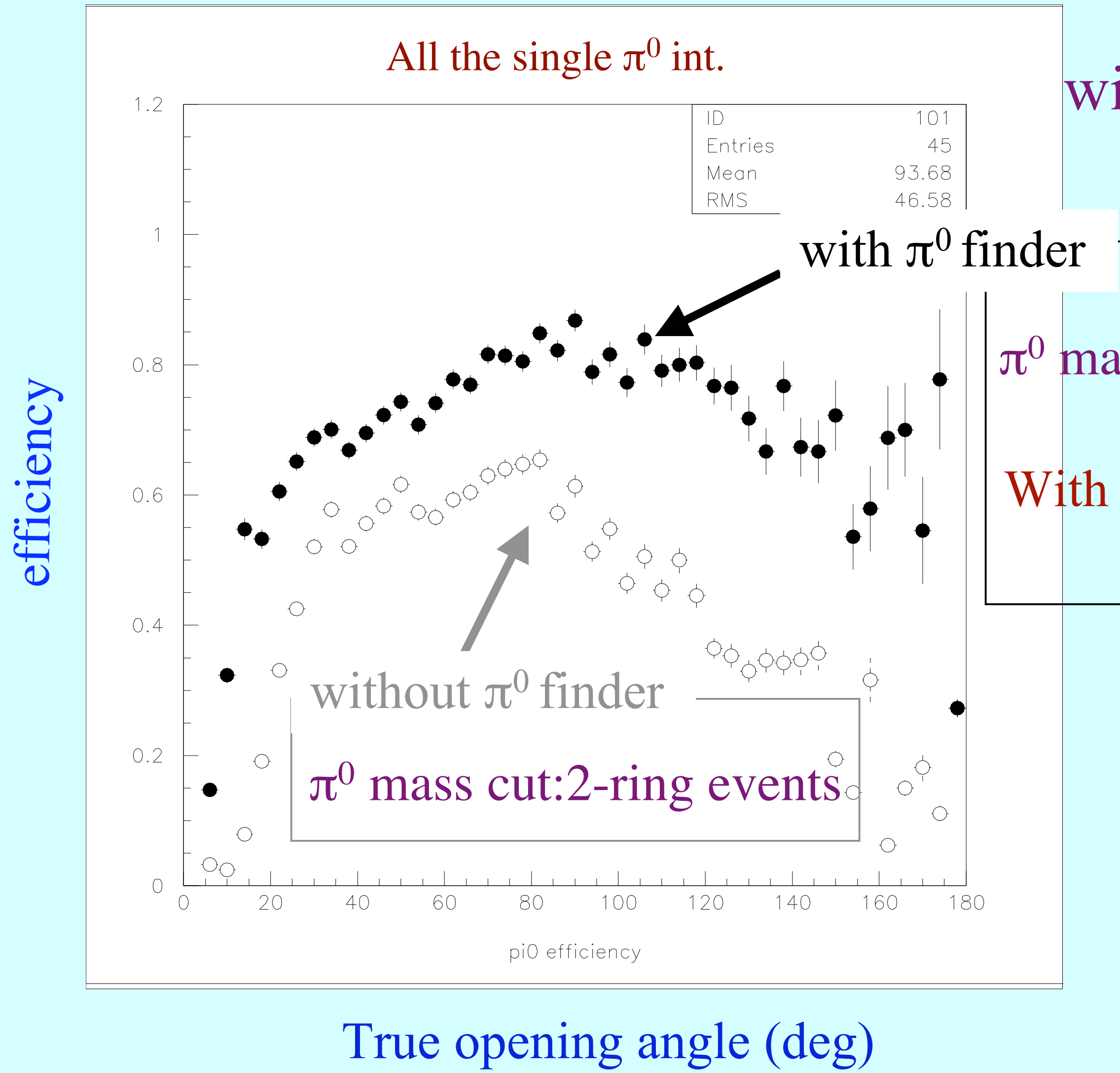
inefficiency due to overlap

inefficiency due to weak 2nd ring



π^0 efficiency

- π^0 detection efficiency with standard SK + π^0 finder



with π^0 finder

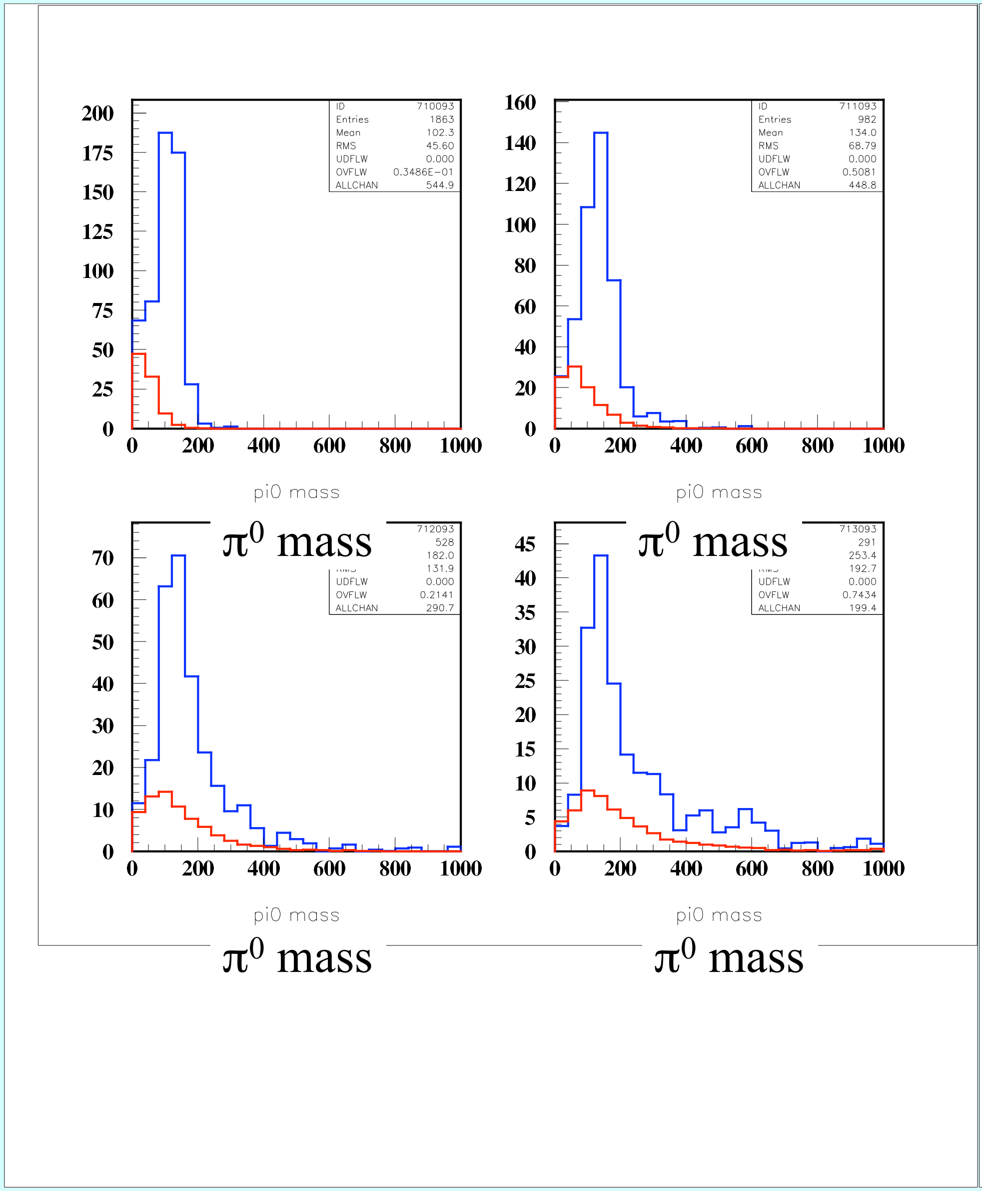
w/o π^0 finder

π^0 mass cut:1- and 2-ring events

With atmospheric neutrino spectra

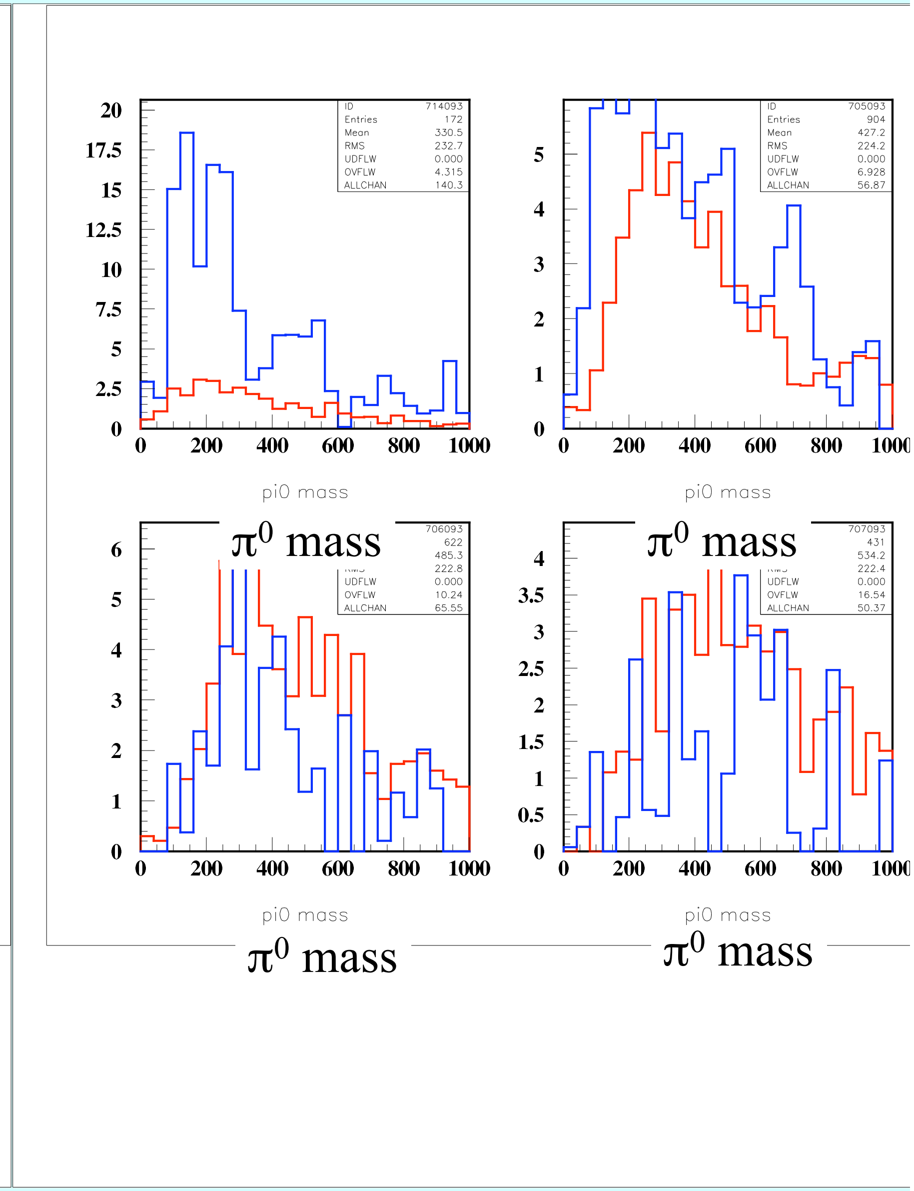
- Useful Variables
  - π^0 mass

All the distributions of useful variables are obtained with neutrino oscillation on with CPV phase angle $+45^0$



π^0 mass π^0 mass

π^0 mass π^0 mass



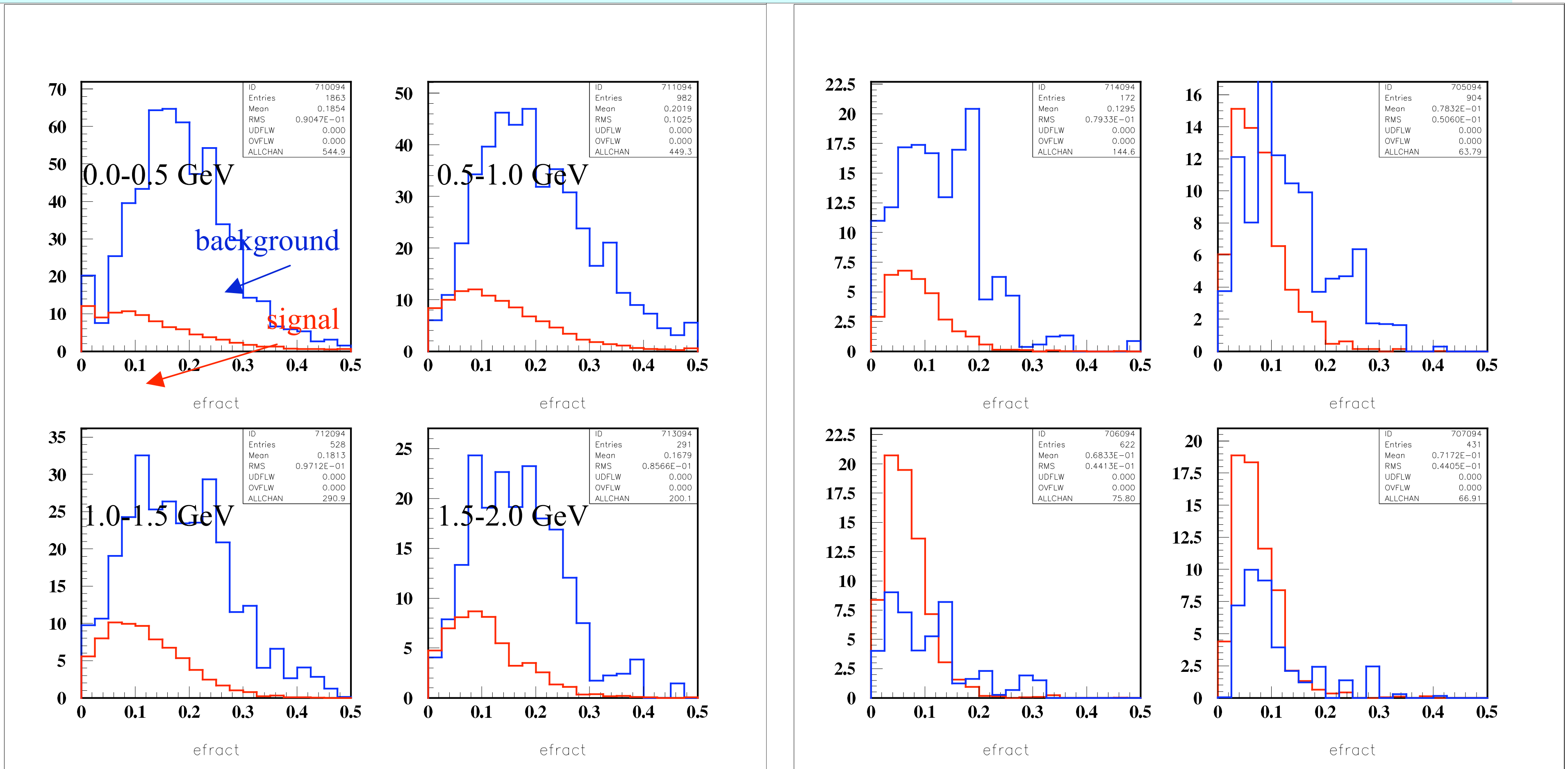
π^0 mass π^0 mass

π^0 mass π^0 mass

Variables

- Energy fraction of 2nd ring

Fake ring has less energy than real one

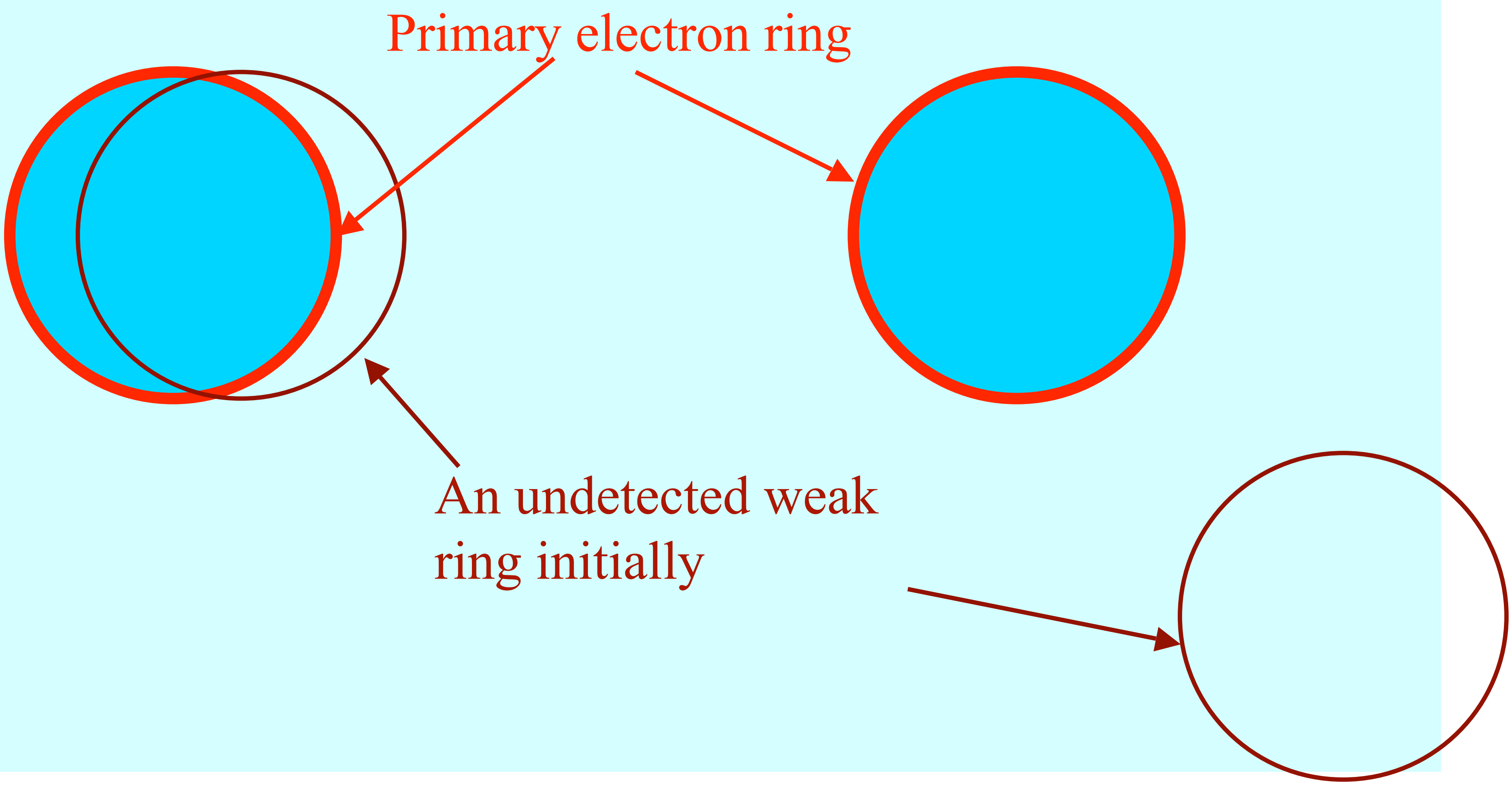


- Difference between log of two π^0-likelihood (wide vs. forward)

- One algorithm optimized to find an extra ring near the primary ring (forward region)

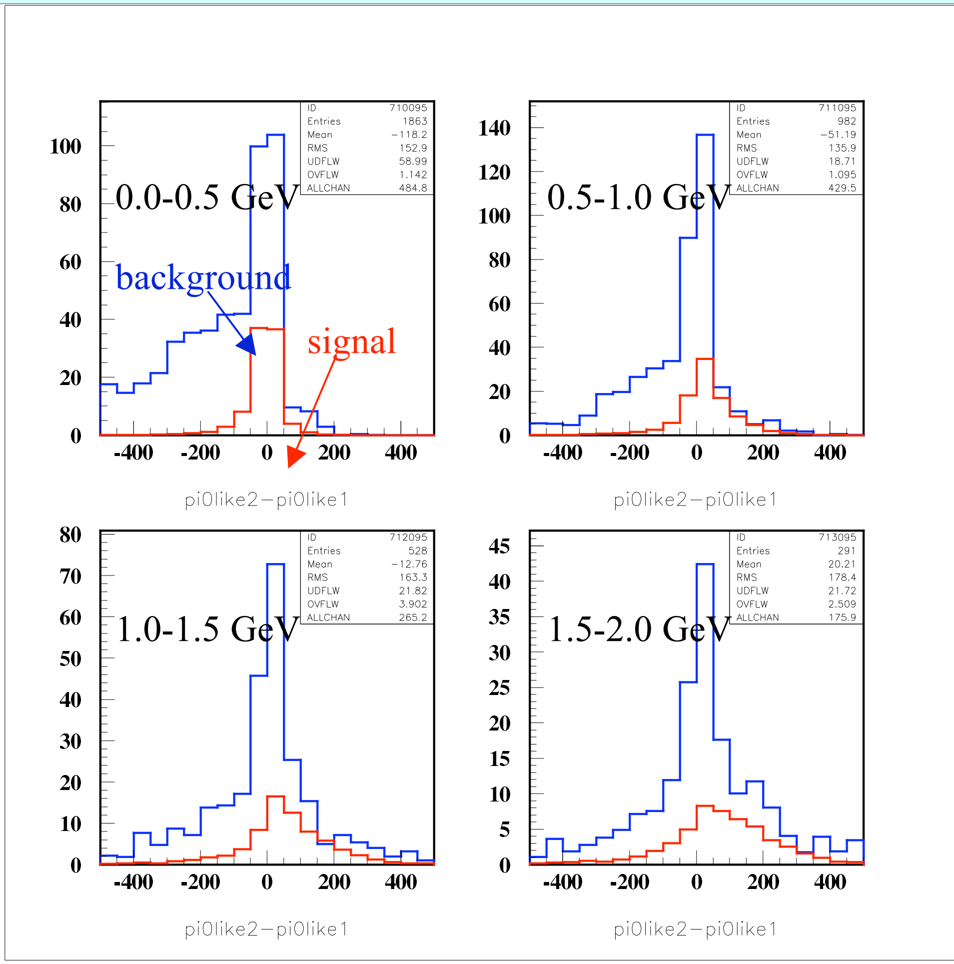
- Another algorithm optimized to find an extra ring in wider space (wide region)

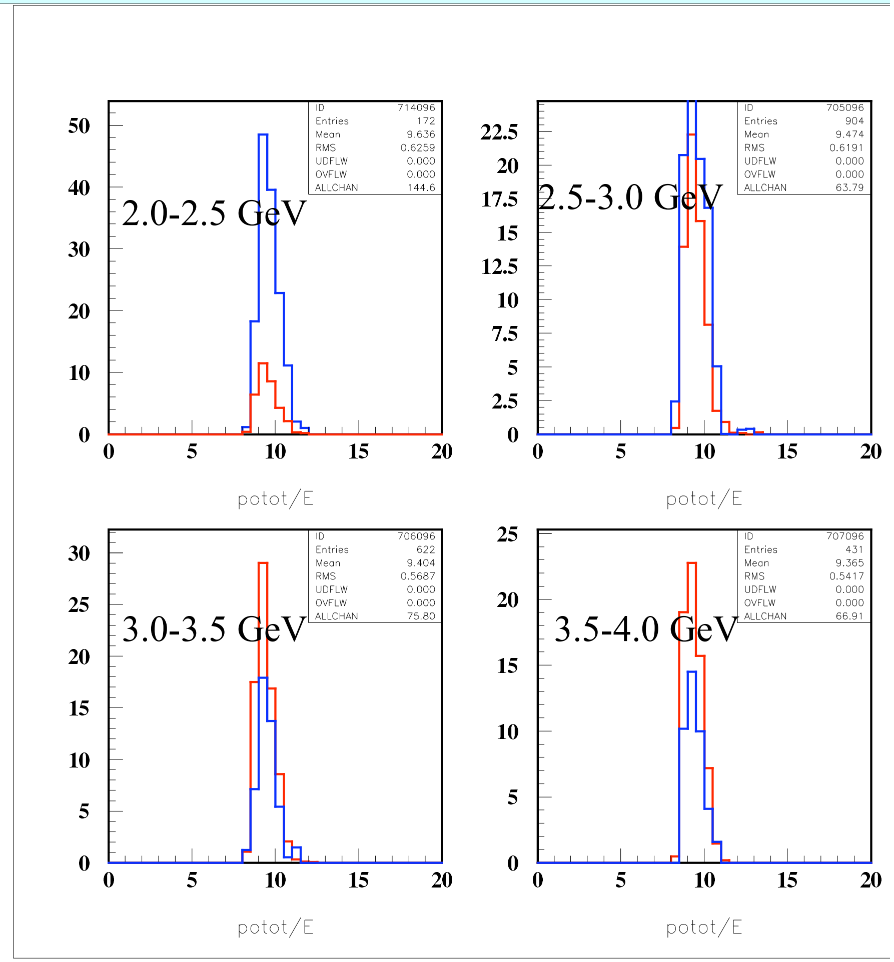
- See the difference ln π^0-likelihood (forward) - ln π^0- likelihood (wide)



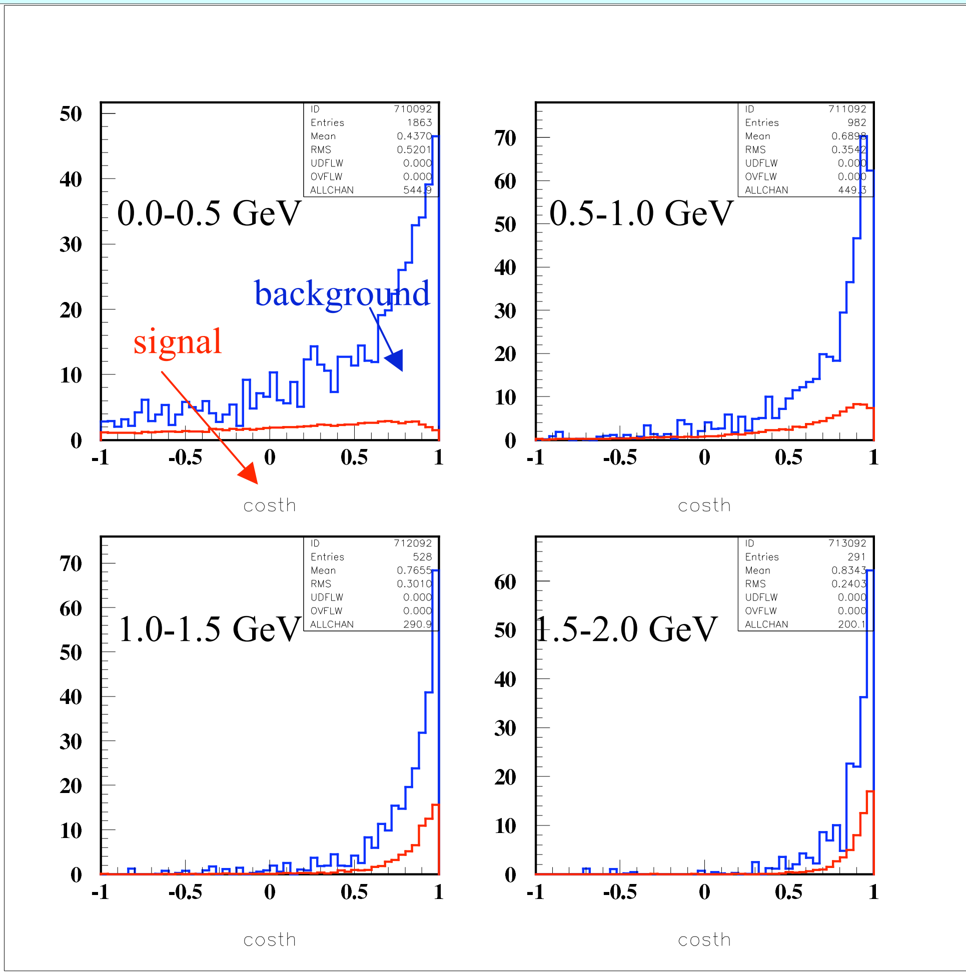
Variables

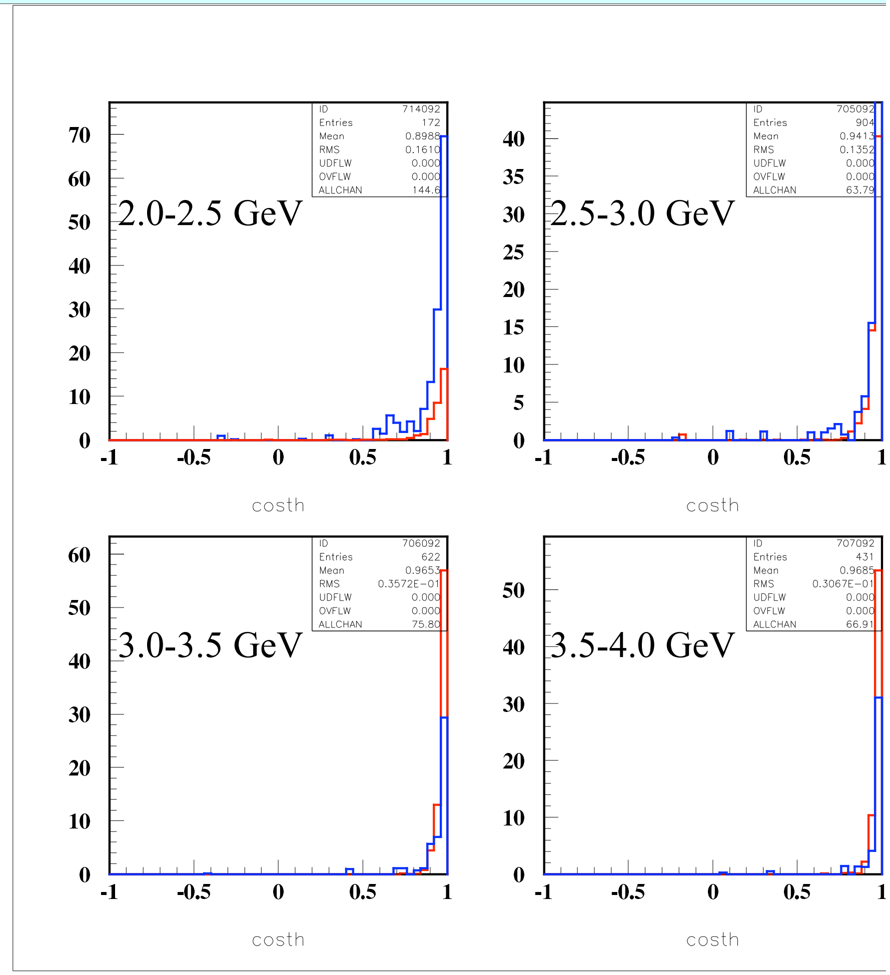
- Difference between log of two π^0-likelihood (wide vs. forward)





- costh = cos θ_e

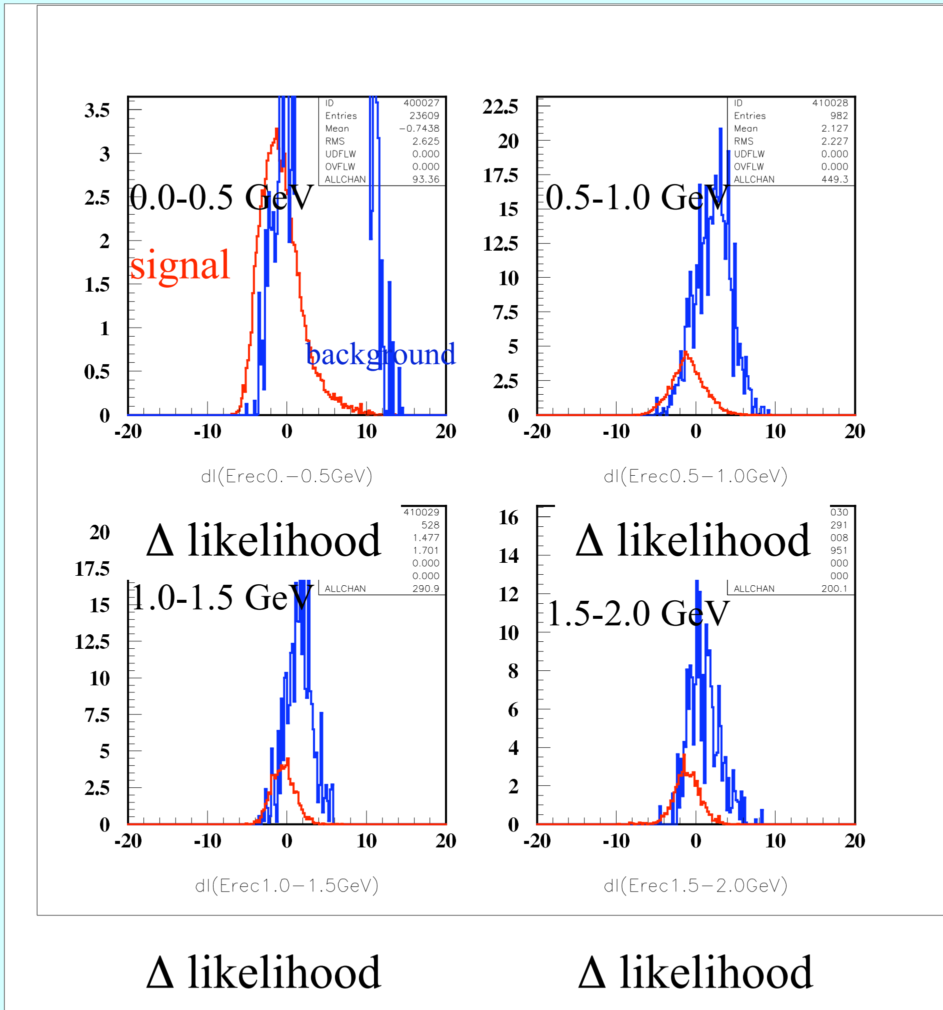


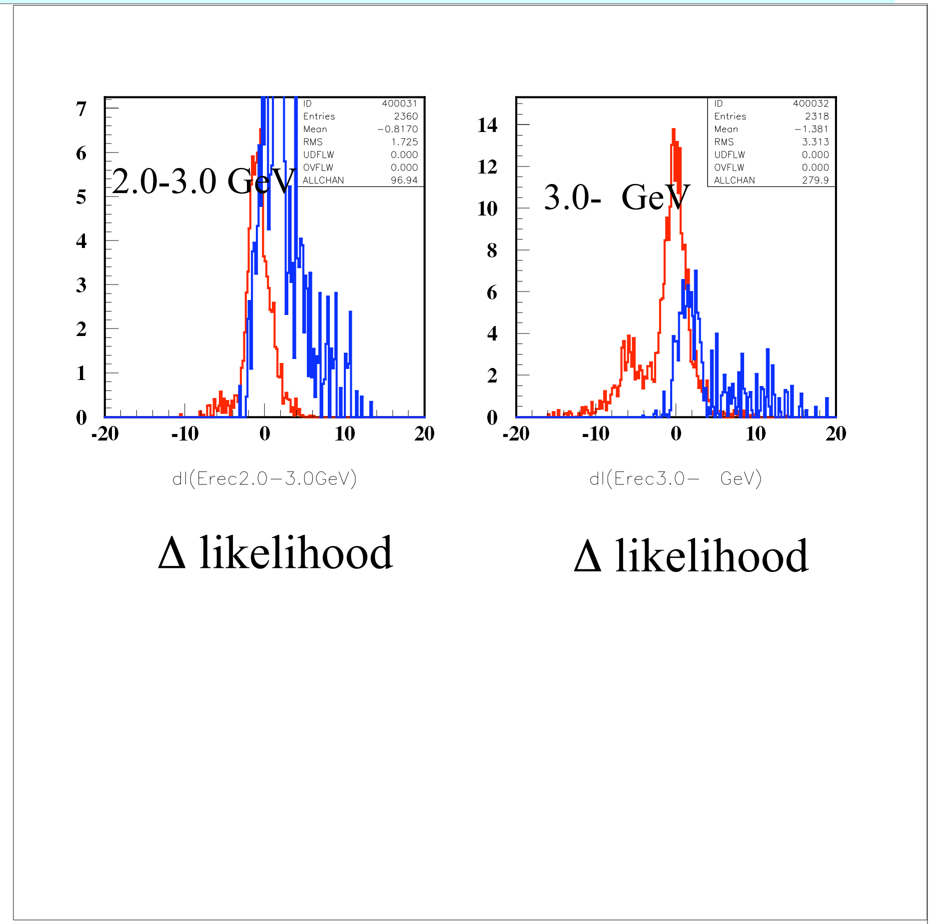


Likelihood C

Trained with ν_e CC events for signal, ν_μ CC/NC & $\nu_{e,\tau}$ NC for bkg

- Δ ln likelihood distributions Difference in ln likelihood between sig and bkg

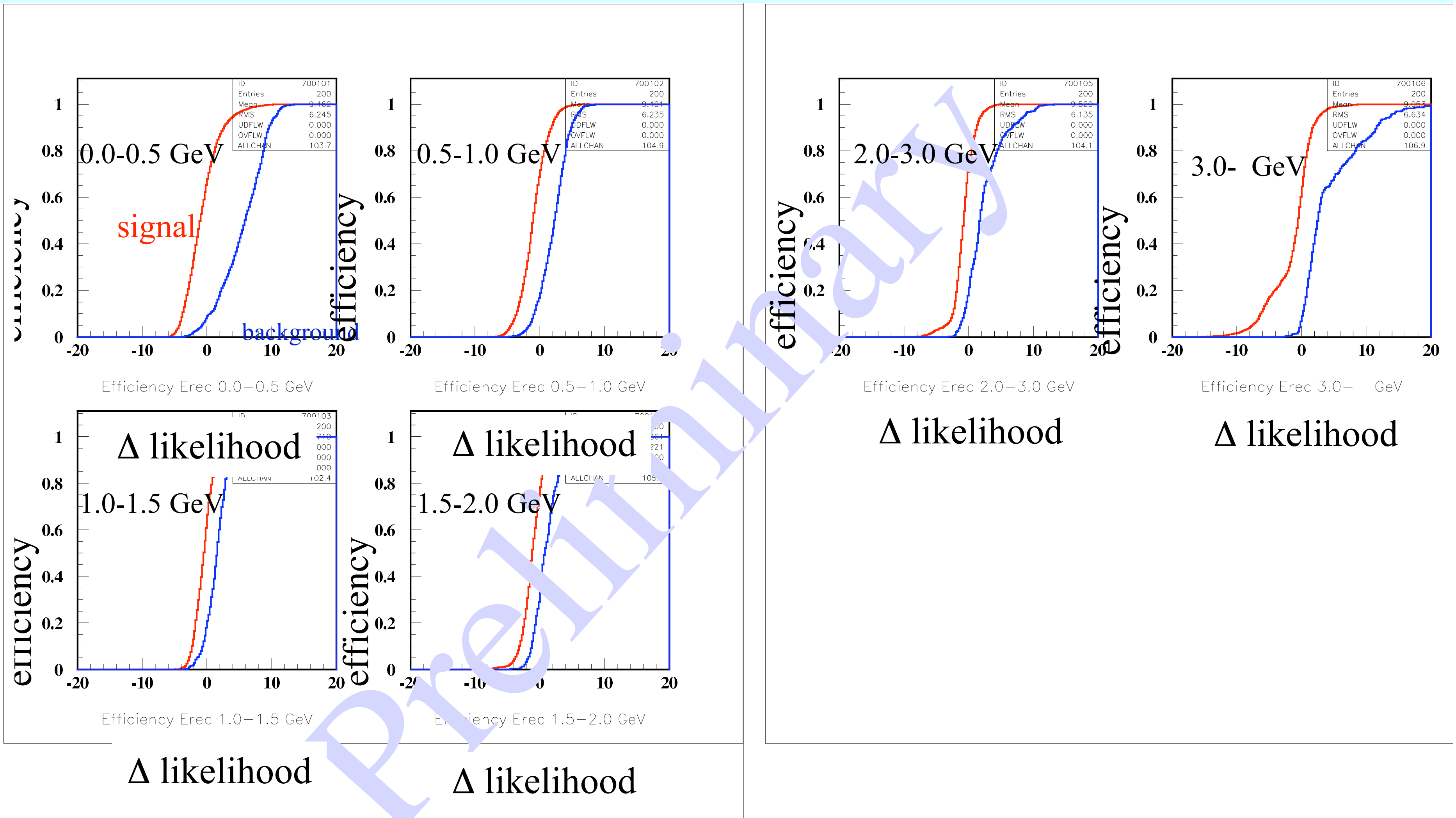




Likelihood (

Trained with ν_e CC events for signal, ν_μ CC/NC & $\nu_{e,\tau}$ NC for bkg

- Efficiency of a cut on Δ ln likelihood (signal vs background)

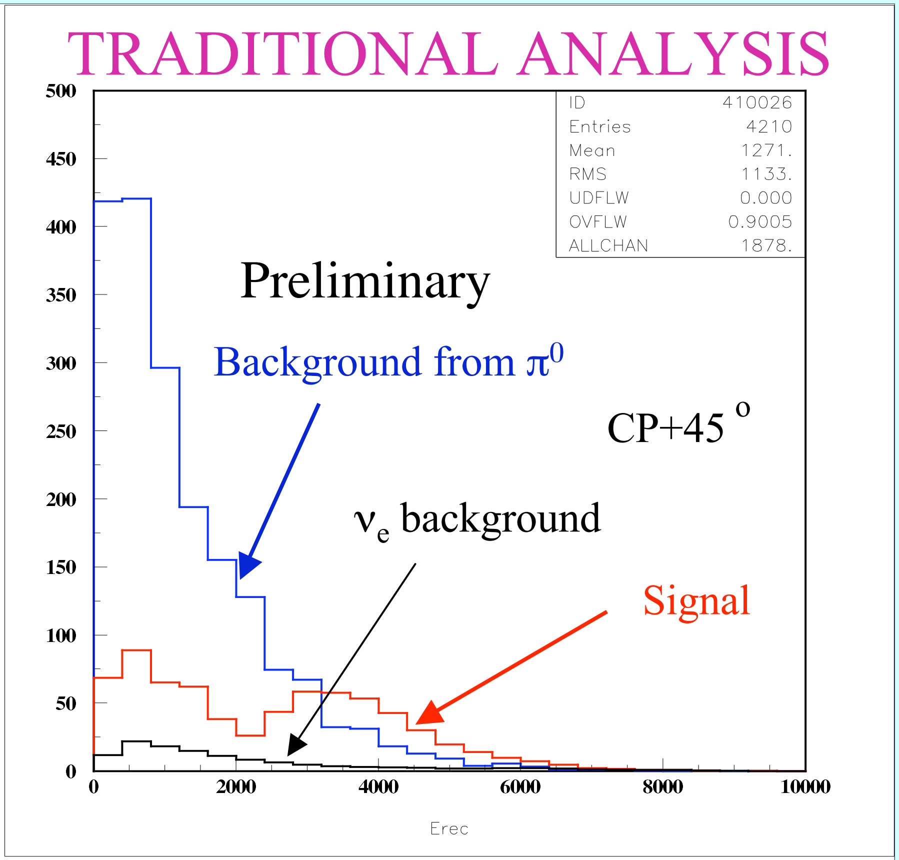


Signal/Background

ν_e CC for signal ; all $\nu_{\mu,\tau,e}$ NC , ν_e beam for background

Effect of cut on Δ likelihood

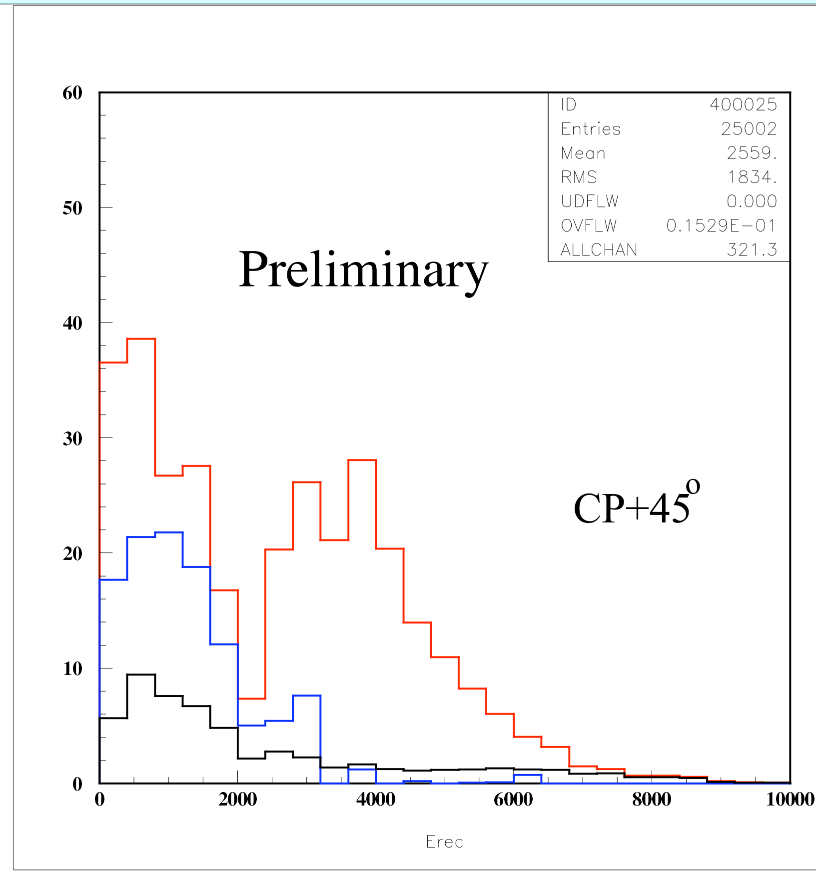
No Δlikelihood cut (100% signal retained)



E_{rec}

Signal 700 ev Bkgs 2005
(1878 from π^0+others)
(127 from ν_e)

Δlikelihood cut (~50% signal retained)



E_{rec}

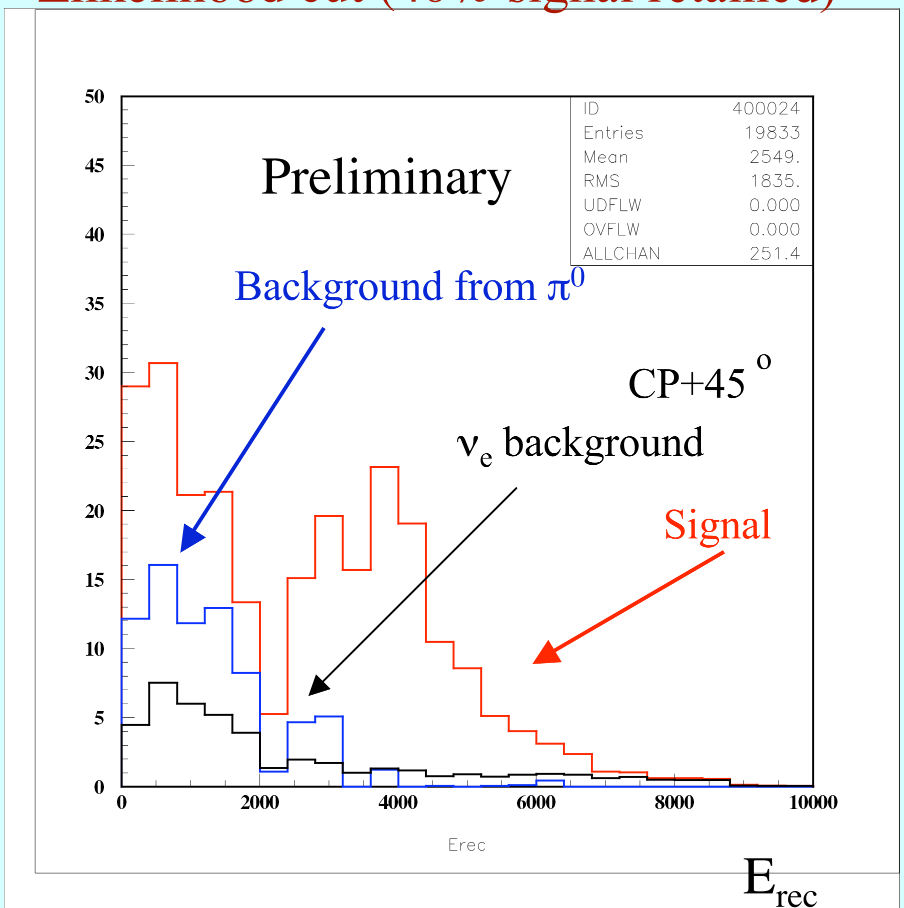
Signal 321 ev Bkgs 169
(112 from π^0+others)
(57 from ν_e)

Signal/Background

Effect of cut on Δ likelihood

ν_e CC for signal ; all $\nu_{\mu,\tau,e}$ NC , ν_e beam for backgrounds

Δlikelihood cut (40% signal retained)

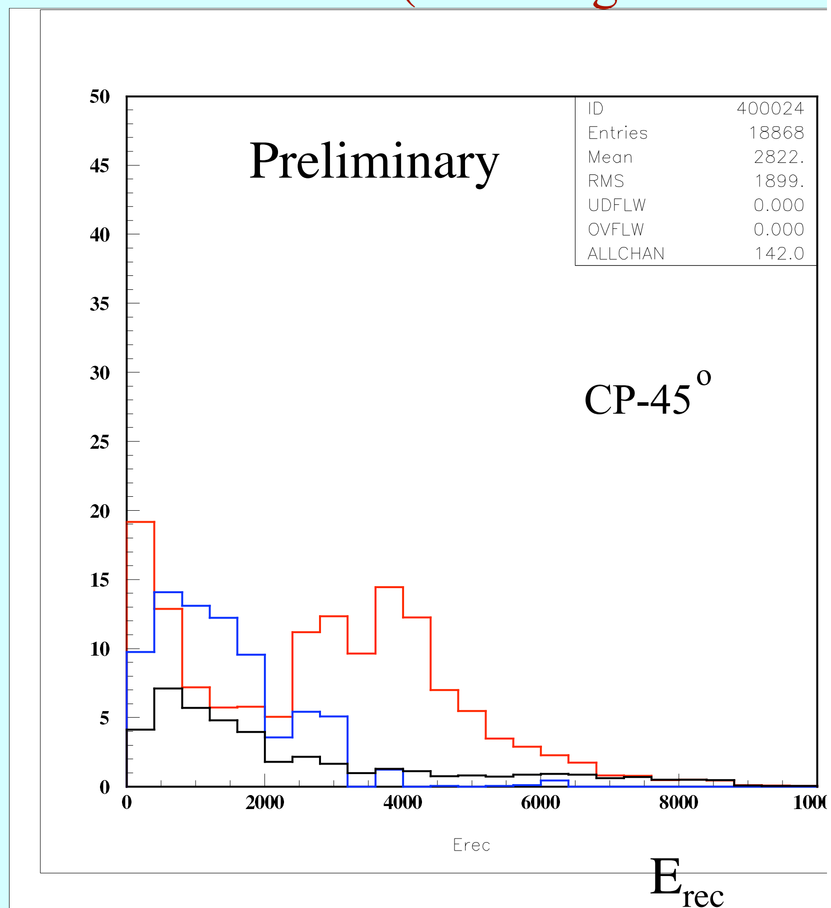


Signal 251 ev Bkgs 118

(74 from π^0+others)

(44 from ν_e)

Δlikelihood cut (~40% signal retained)



Signal 142 ev Bkgs 118

(75 from π^0+others)

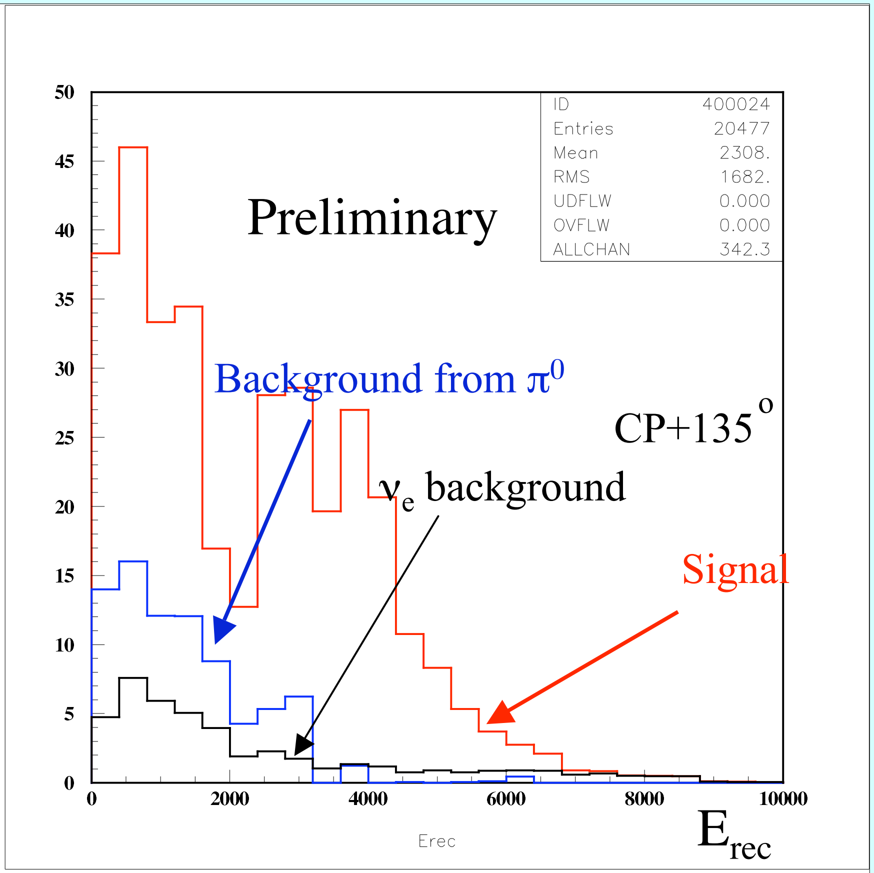
(43 from ν_e)

Signal/Background

ν_e CC for signal ; all $\nu_{\mu,\tau,e}$ NC , ν_e beam for backgrounds

- Effect of cut on likelihood

Δlikelihood cut (~40% signal retained)

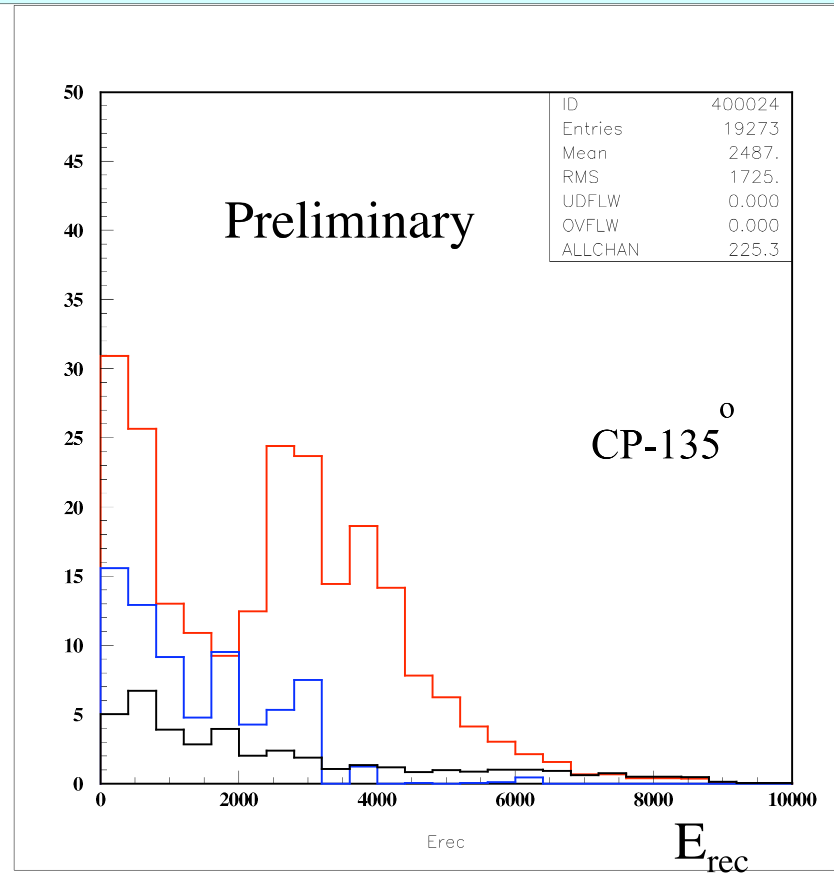


Signal 342 ev Bkgs 126

(81 from π^0+others)

(45 from ν_e)

Δlikelihood cut (~40% signal retained)



Signal 233 ev Bkgs 122

(78 from π^0+others)

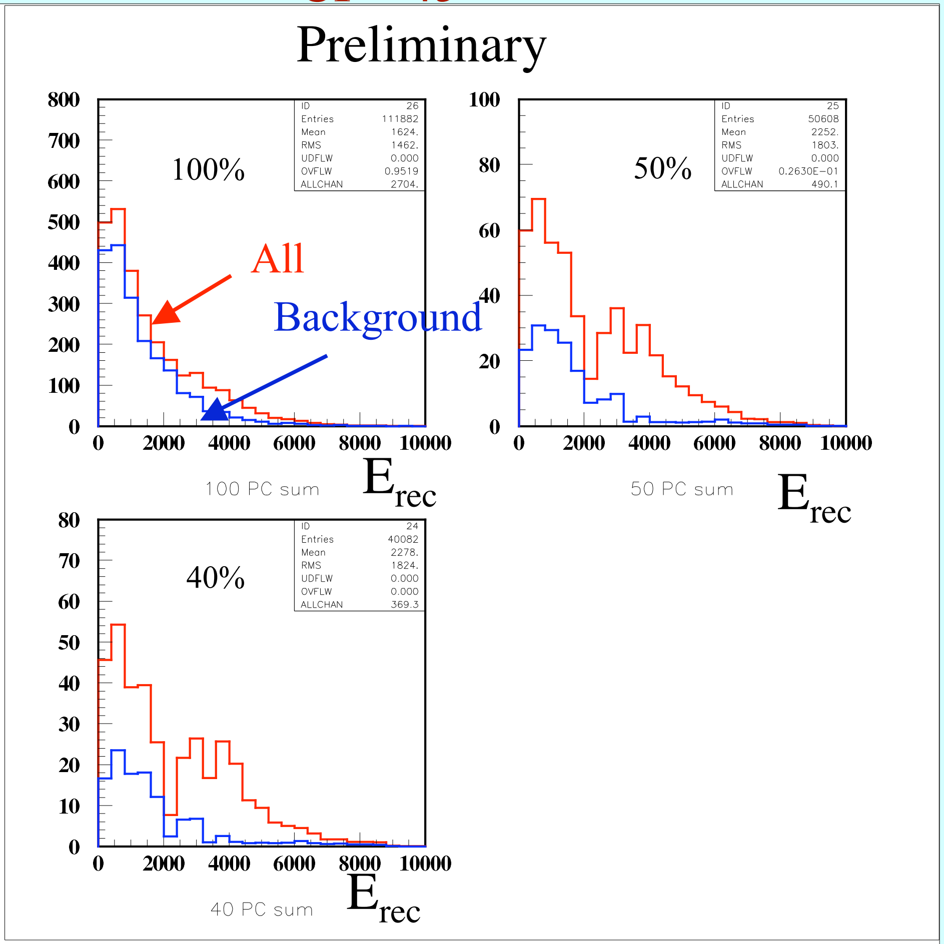
(44 from ν_e)

S/B

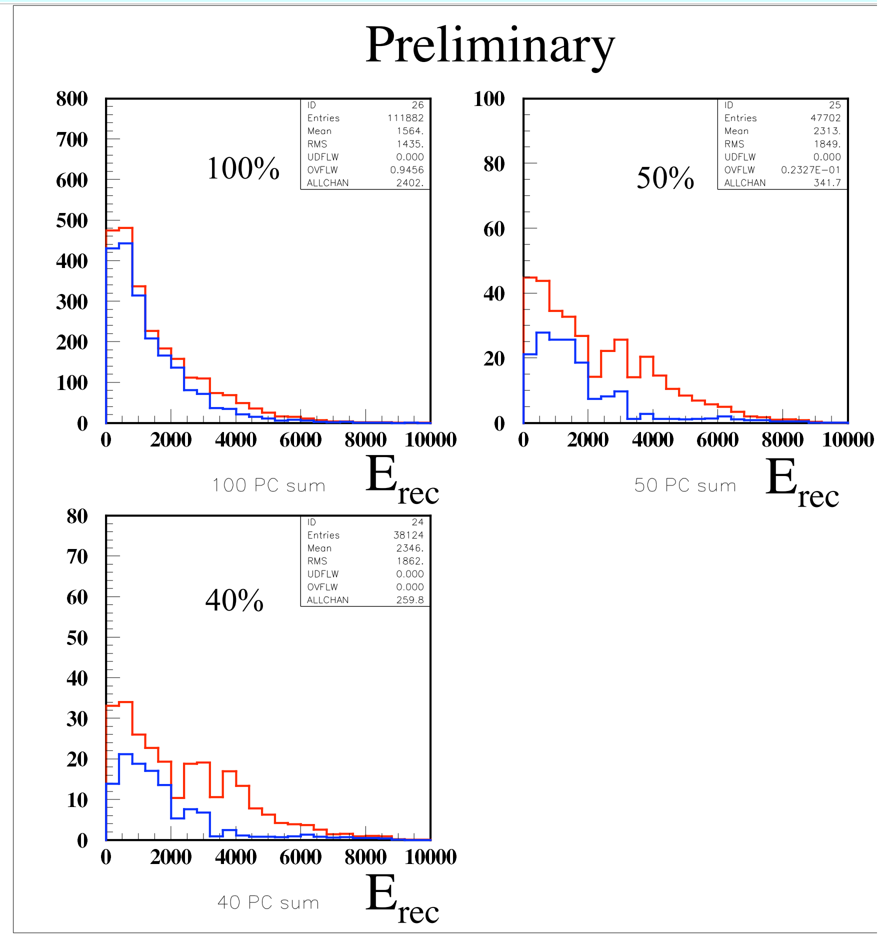
ν_e CC for signal ; all $\nu_{\mu,\tau,e}$ NC , ν_e beam for backgrounds

- Effect of cut on likelihood

CP +45^o



CP-45^o

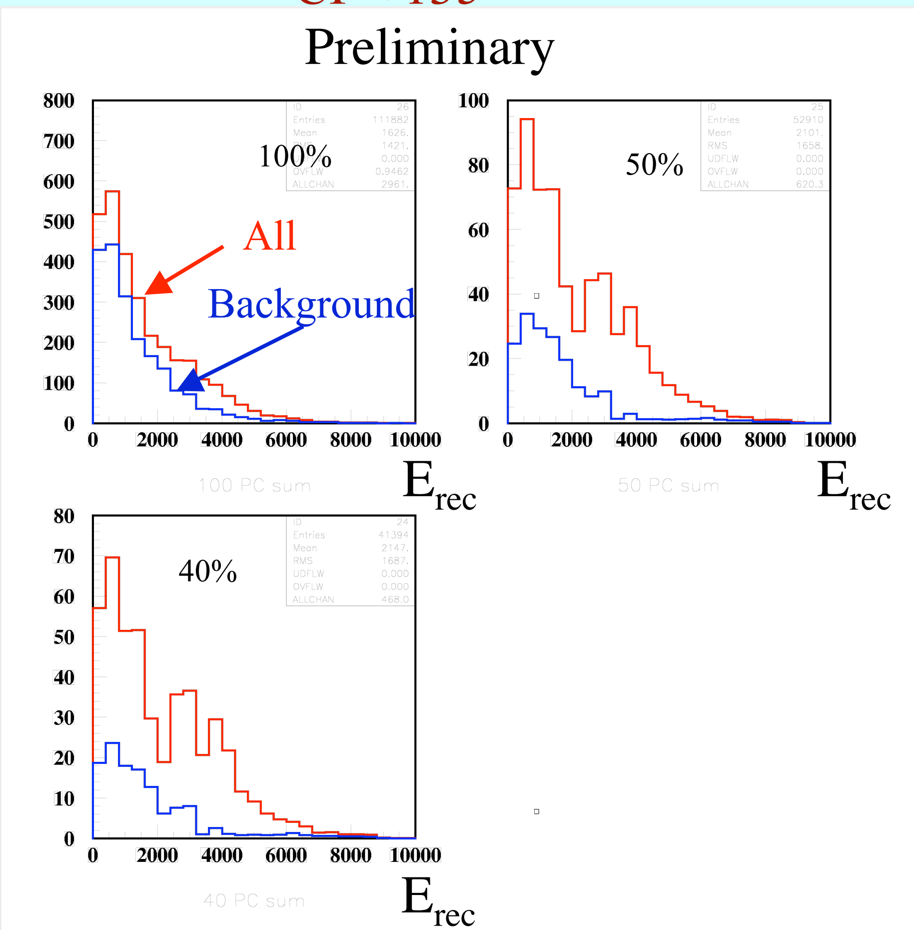


S/B

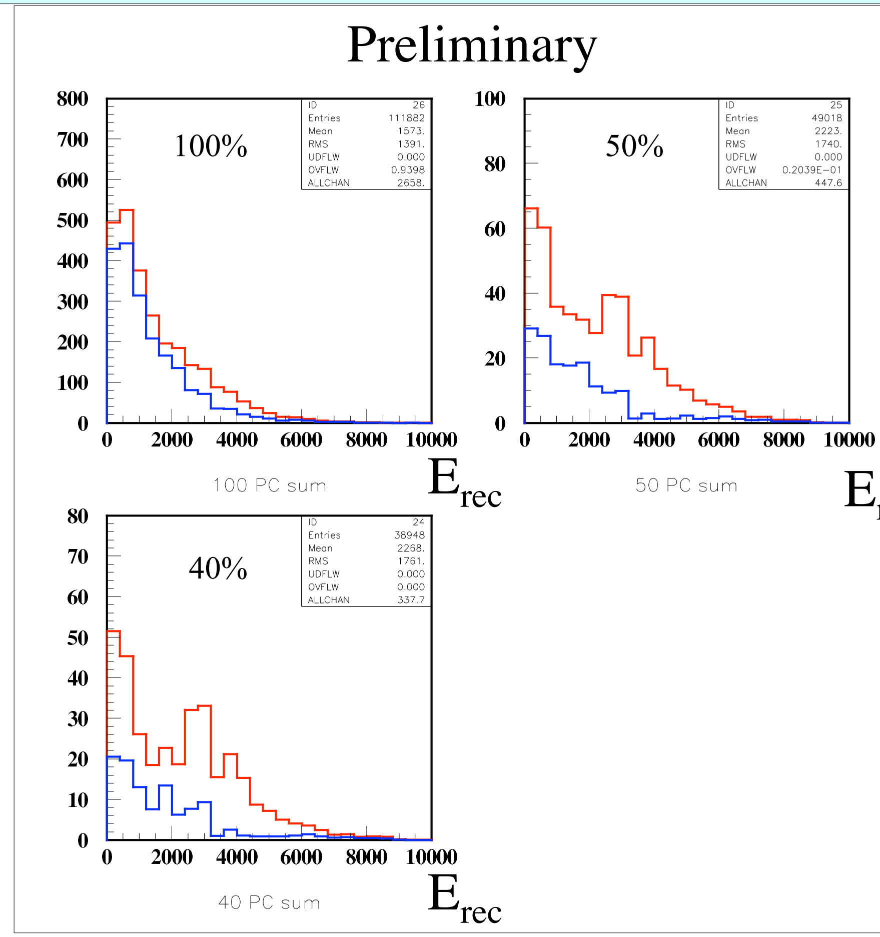
Effect of cut on likelihood

ν_e CC for signal ; all $\nu_{\mu,\tau,e}$ NC , ν_e beam for backgrounds

CP +135°



CP-135°



Signal/background

_ S/B

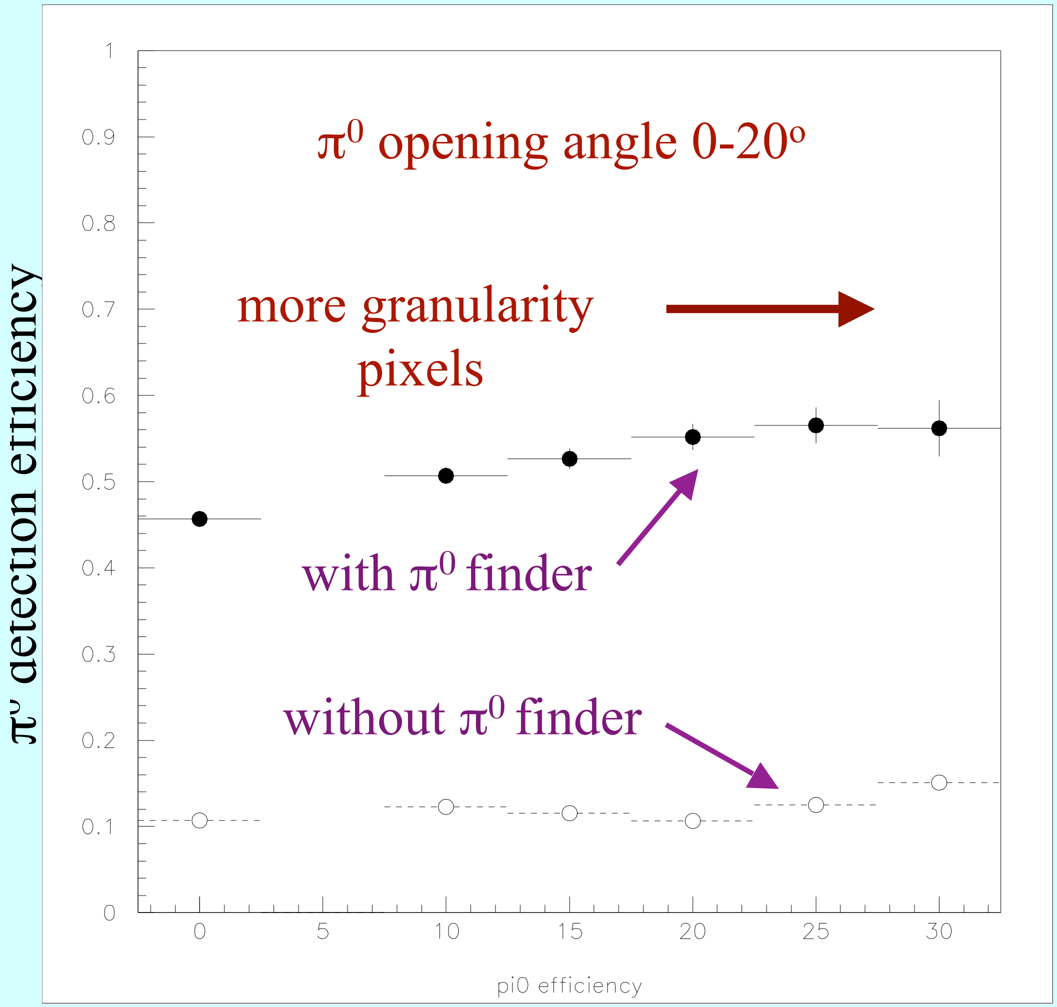
Summary of BNL superbeam@UNO

CP phase	Signal	Bkg	Effic	Signal	Bkg	Beam ν_e
0^o	ν_e CC	ν_μ all, ν_e NC	40%	178	75	43
-135^o	ν_e CC	ν_μ all, ν_e NC	40%	233	78	44
$+135^o$	ν_e CC	ν_μ all, ν_e NC	40%	342	81	45
-45^o	ν_e CC	ν_μ all, ν_e NC	40%	142	75	43
$+45^o$	ν_e CC	ν_μ all, ν_e NC	$\boxed{100\%}$	$\boxed{700}$	$\boxed{1878}$	$\boxed{127}$
			50%	321	112	57
	with traditional water Chrenkov cuts		40%	251	74	44

• Granularity and π^0 efficiency

Expected improvement with UNO?

Compared with SK size detector



Minimum distance to wall in π^0 direction (m)

- For smaller π^0 opening angle finer granularity needed
- π^0 efficiency improves when min. distance increases (up to 20%)
- See power of π^0 finder

One issue I never mentioned before is that 2/3 of UNO volume is cover only 10% by PMTs and that we nee to check the detector performance w 10% PMT coverage

Conclusions

- UNO has great potential for future physics and it is moving steadily with steady increase in the membership from 49 to 94
- Realistic MC simulation studies have been performed for BNL very long baseline with a water Cherenkov detector and it was found that BNL VLB combined with UNO seems to DO GREAT JOB – Very exciting news but need confirmation
- It was demonstrated that there is some room to improve S/B ratio beyond the standard water Cherenkov detector software with currently available software

  - We need to do similar analysis using a MC package that simulates the UNO baseline design (2 x 10% + 40% coverage and size)
  - We may need further improvement of algorithm/software, which is quite possible
  - Detailed studies on sensitivity on oscillation parameters needed
  - A larger detector such as UNO has an advantage over a smaller detector such as SK (we learned a lesson from 1kt at K2K)

A detailed Monte Carlo package for UNO is in preparation!

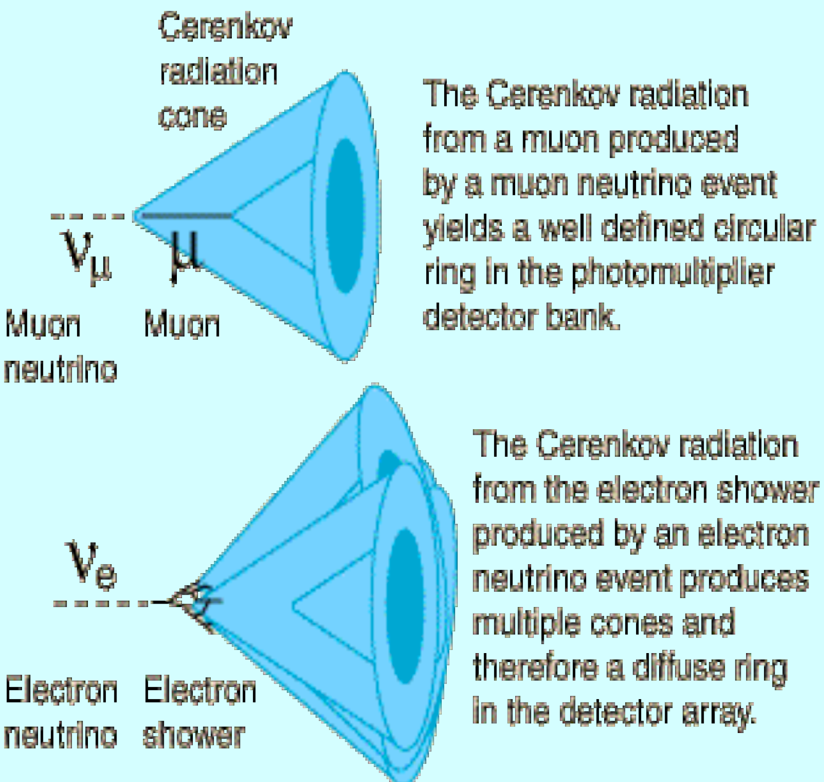
Backup Slides

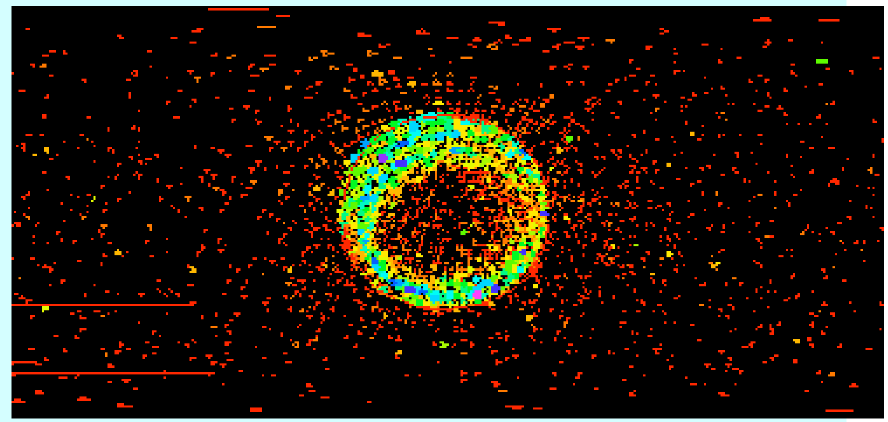
Schedule

	Year -2	Year -1	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
R&D Proposal LOI	↔											
Tech.Proposal		↔										
Excavation			←	—	→	←	→					
Water Containment						←	→	←	→			
PMT Delivery			←	—	—	—	→	←	—	→		
Preparation			←	—	—	—	—	—	→			
Installation										↔	↔	
Water Fill												↔
							Contingency			↔		

Electron-like vs. muon-like ring

How do we detect atmospheric muon and electron neutrinos ?





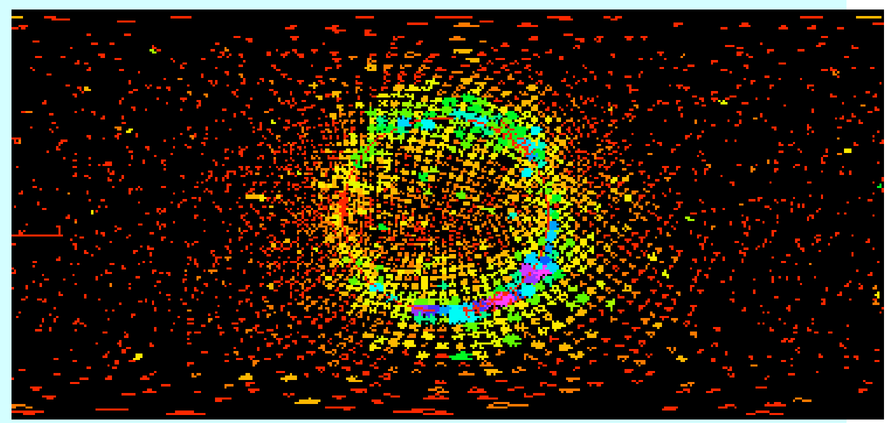
muon-like ring

Major interactions:

$\nu_e \;\; + n \to \boxed{p} + \boxed{e^-}$

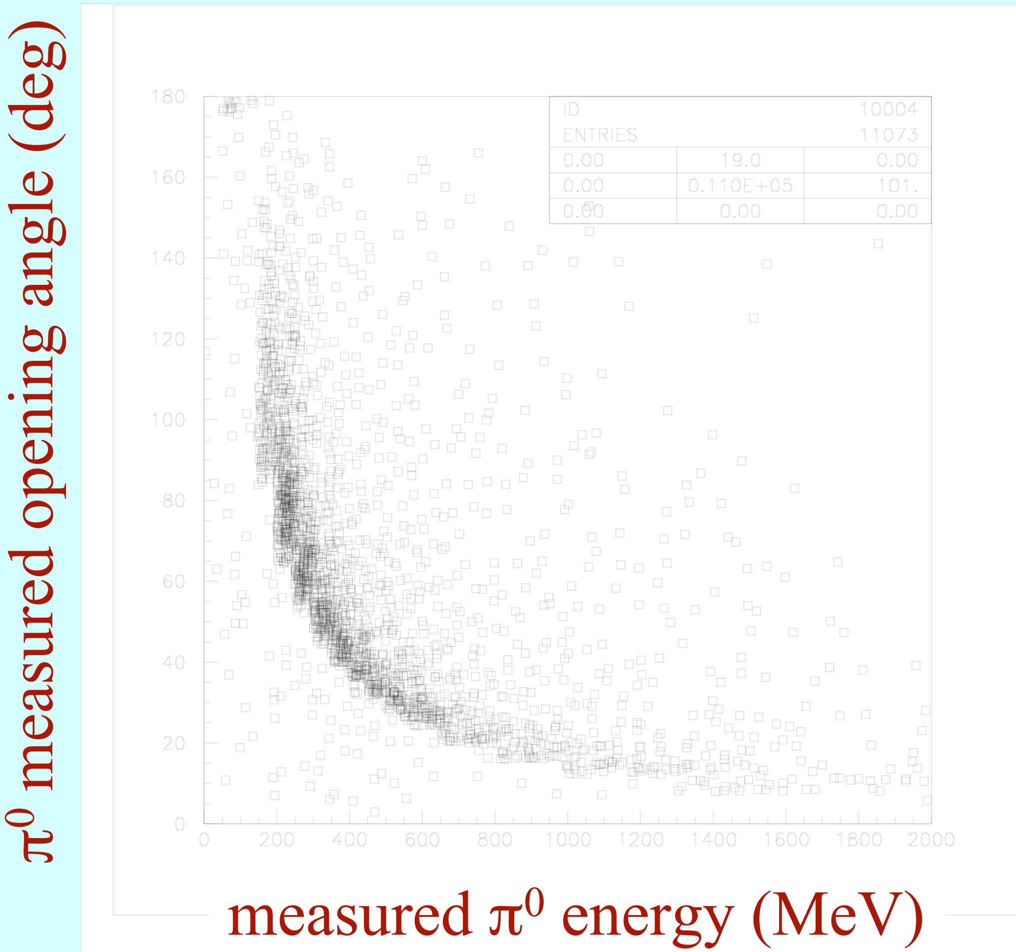
$\nu_\mu \;\; + n \to \boxed{p} + \boxed{\mu^-}$

Most of time invisible



electron-like ring

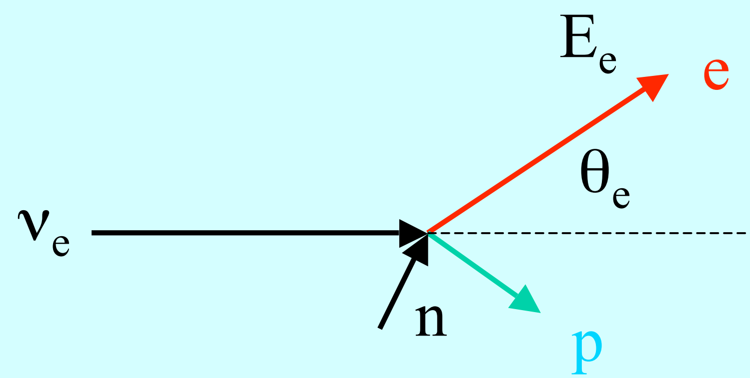
- π^0 efficiency
  - **π^0 opening angle vs. measure π^0 energy**



Note: The energy spectrum of π^0 is that of SK atm. ν interactions

- costh = cos θ_e

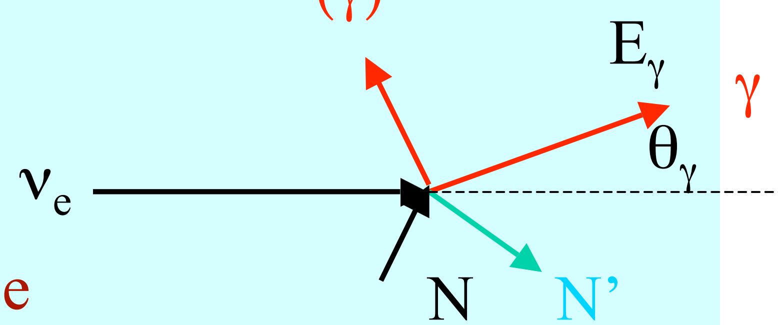
$$E_\nu^{rec} = \frac{m_N E_e}{m_N - (1-\cos\theta_e)E_e}$$



It is not clear why the distributions of costh behave as shown in the following.

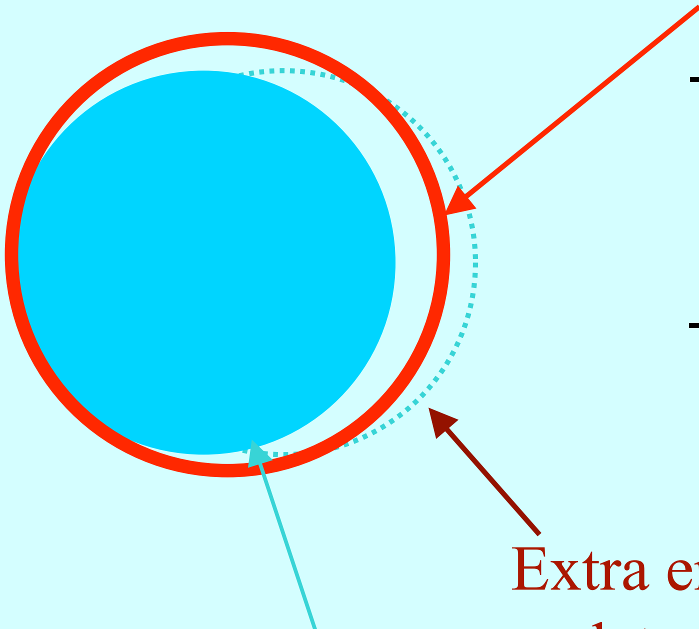
My speculation:

1) The signal events from QE scattering have larger θ_e due to the Fermi motion of the target neutron in oxygen in the low energy region.



2) For lower energy background events, the minimum opening angle is larger. In those events accepted as signal, π^0 decay is very asymmetric and the primary γ carries most of the energy.

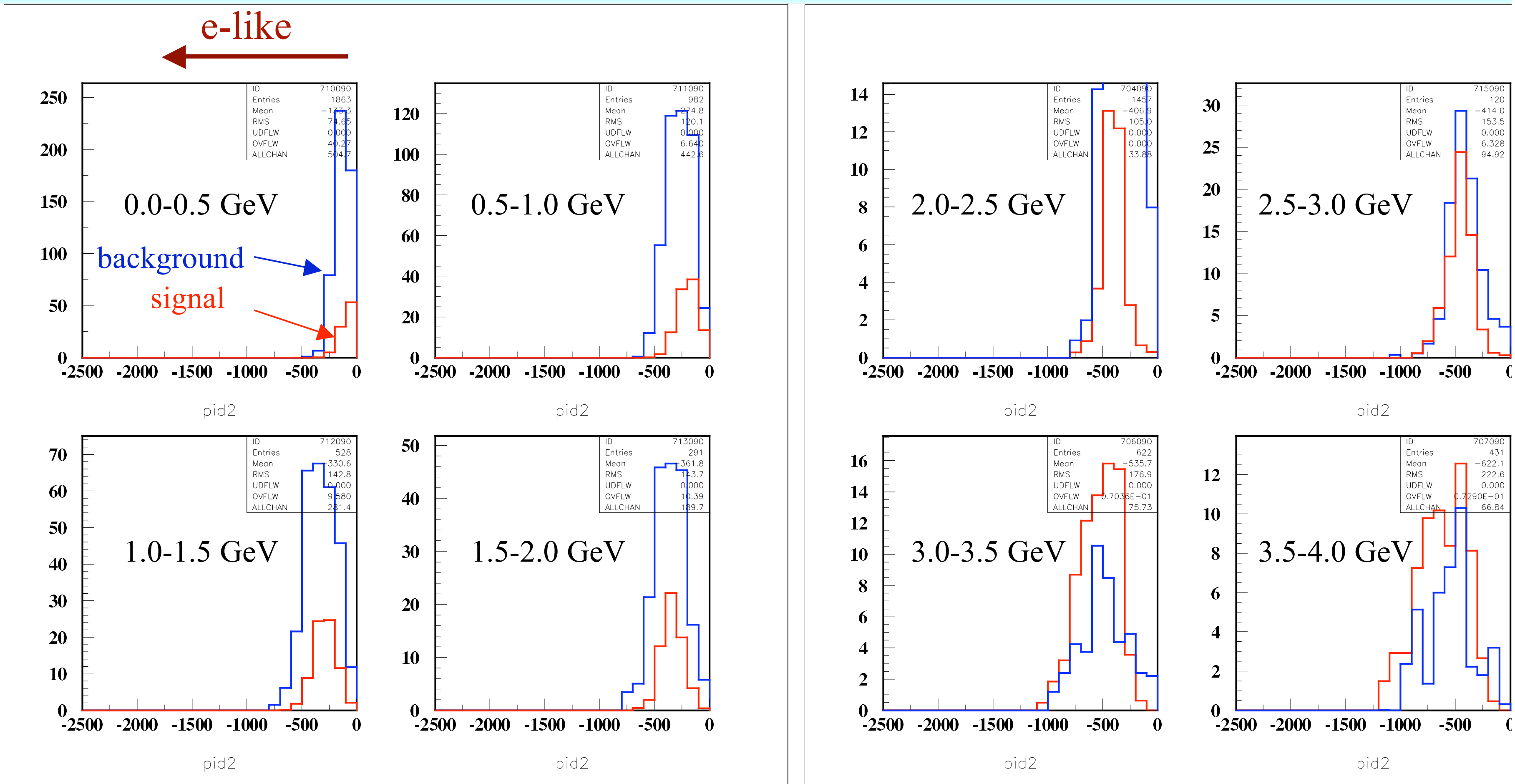
- e-likelihood



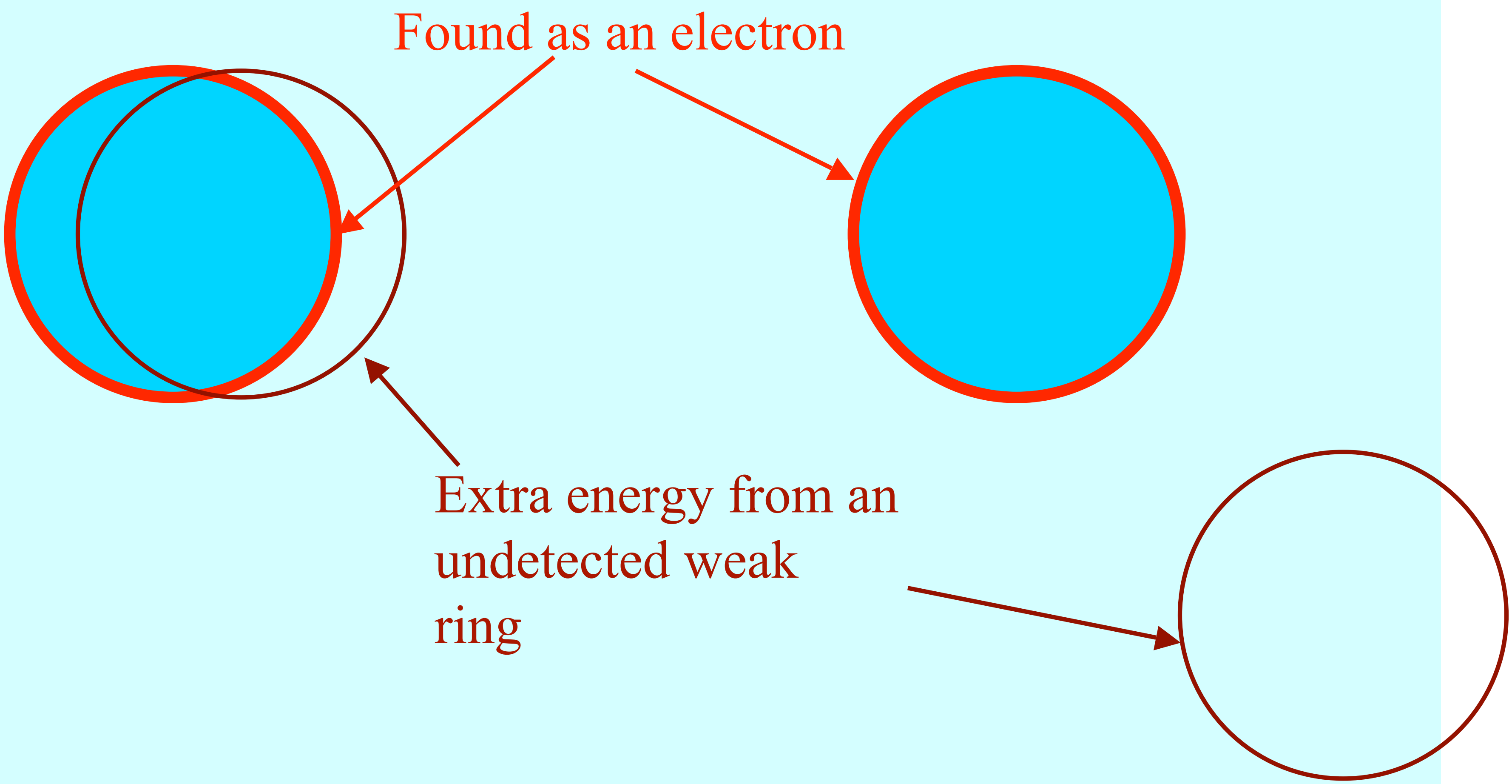
- Two overlapped e-like rings identified as an e-like ring look like a fuzzier electron than an electron at lower energy

- At higher energy multiple particles go into a similar direction and identified as an e-like ring – could look less fuzzy than an electron

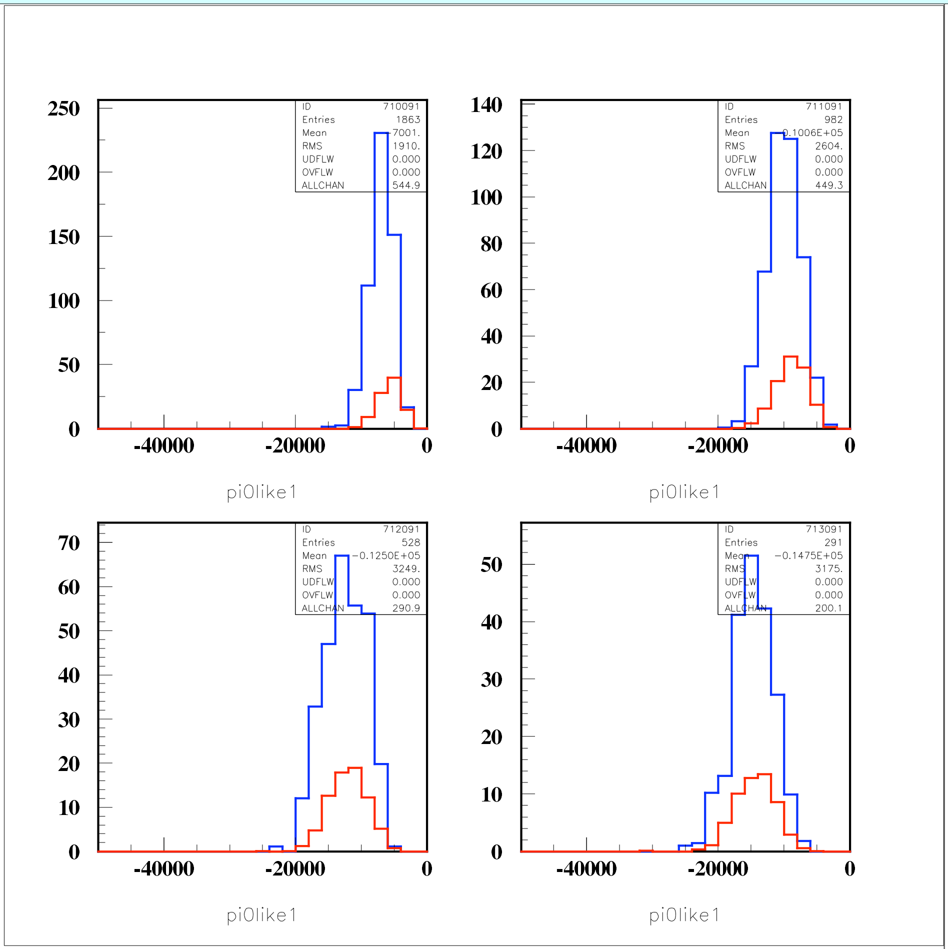
e-likelihood

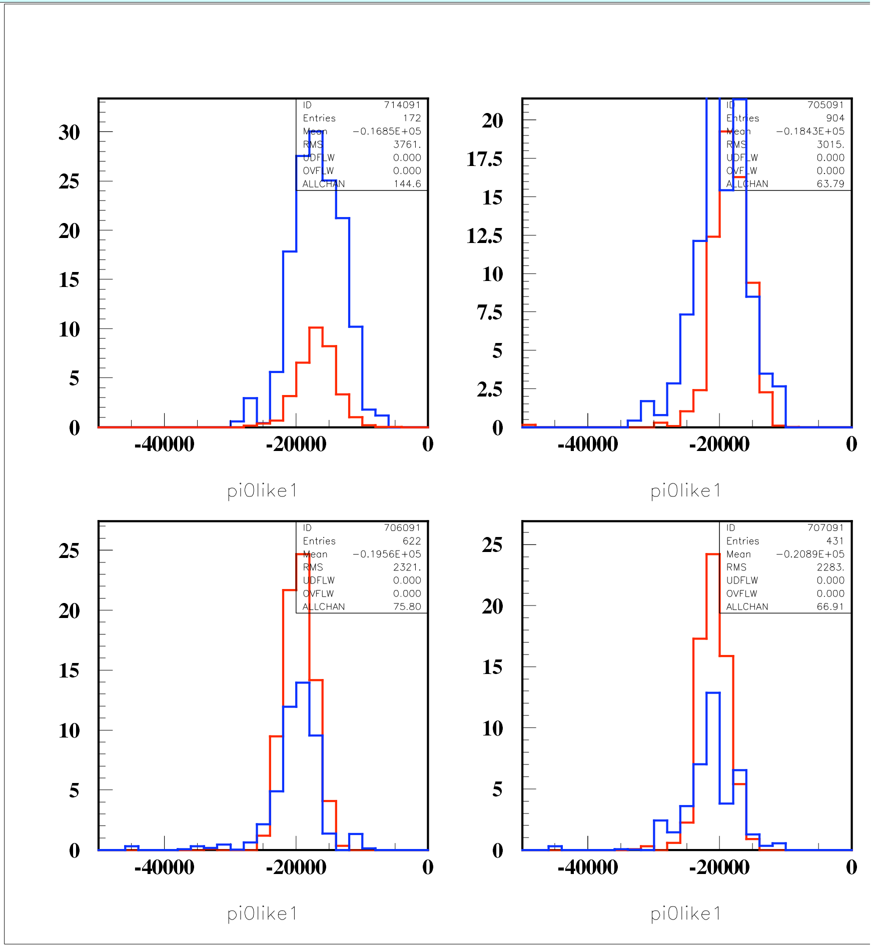


- π^0 likelihood tells whether an event is consistent with a single π^0 event



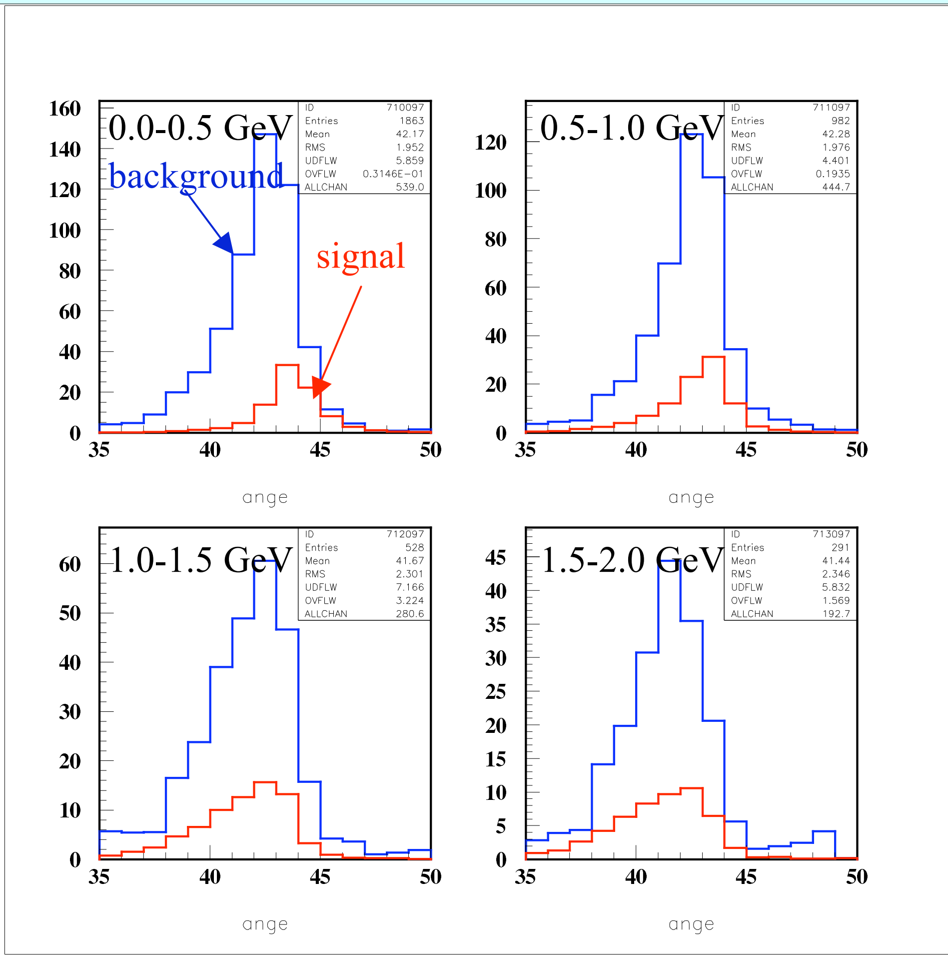
• π^0 likelihood

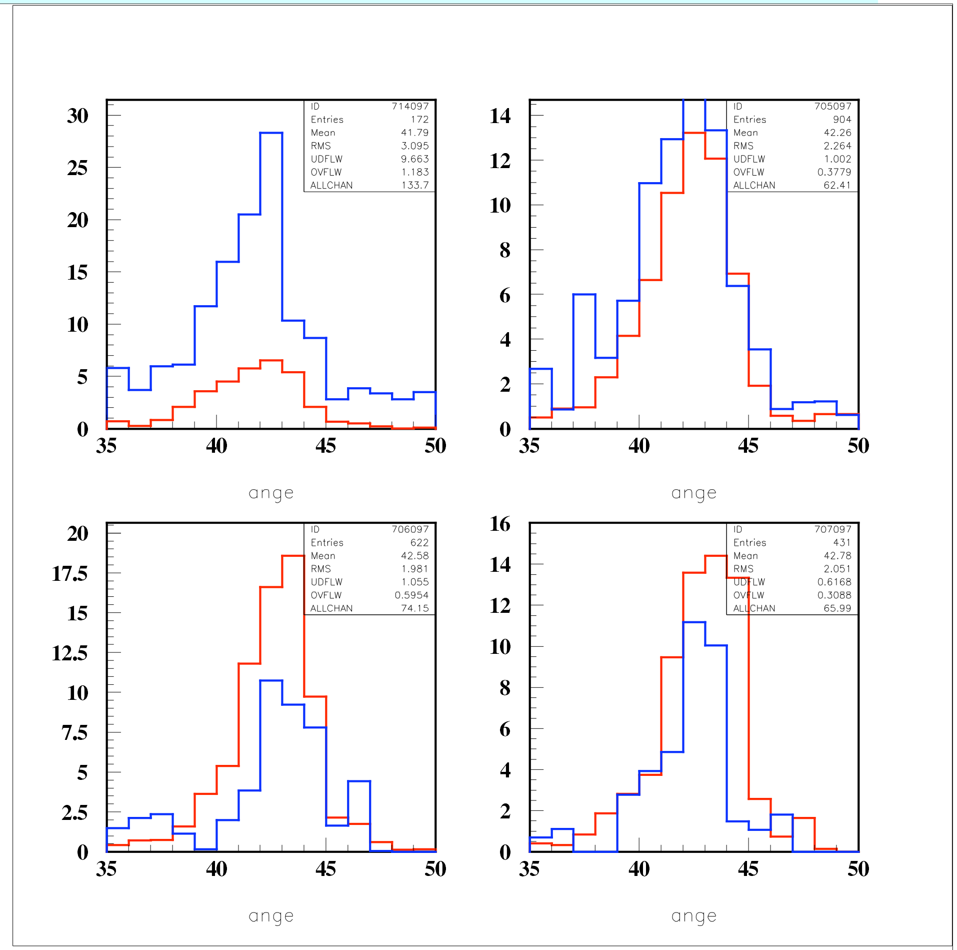




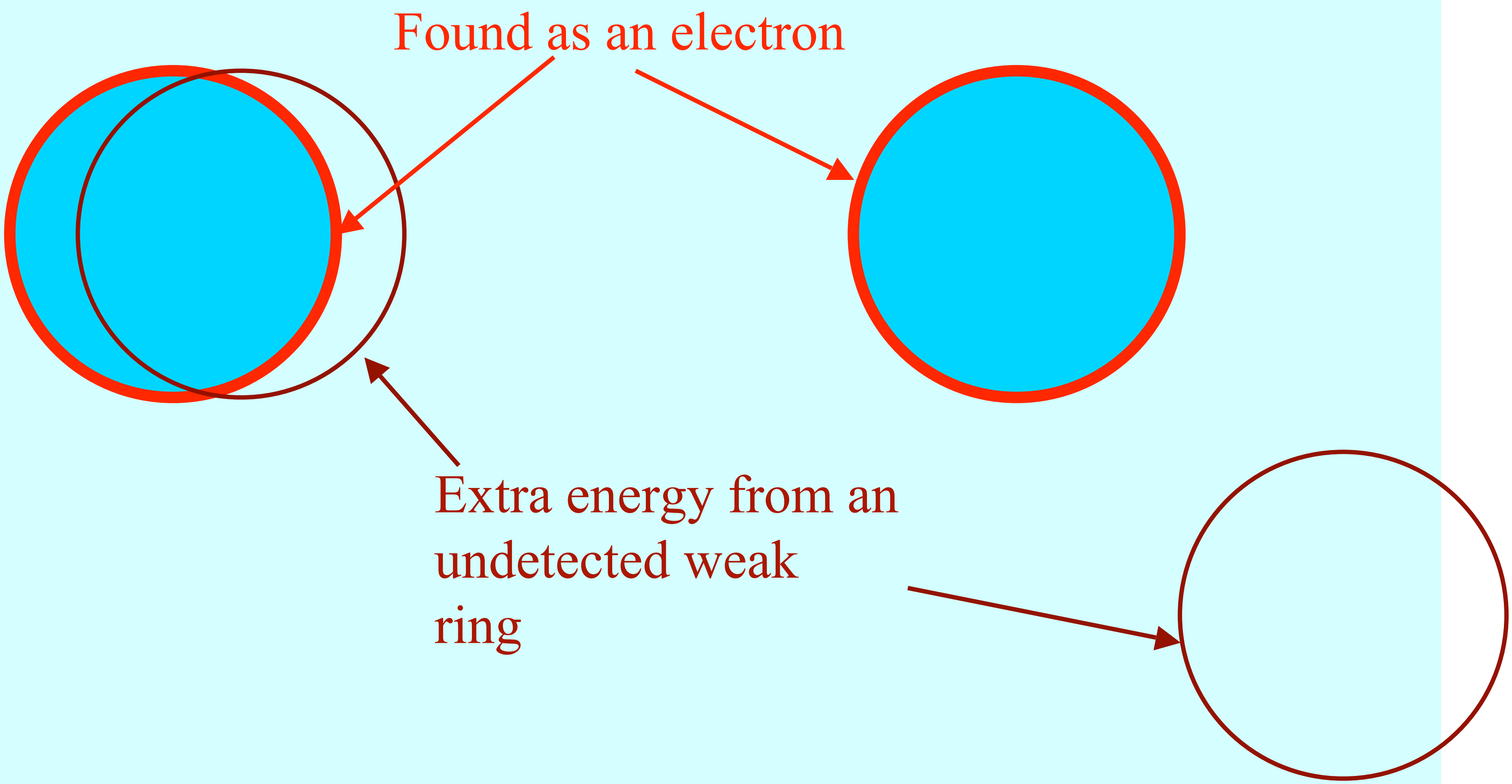
Variables

- Measure Cherenkov angle



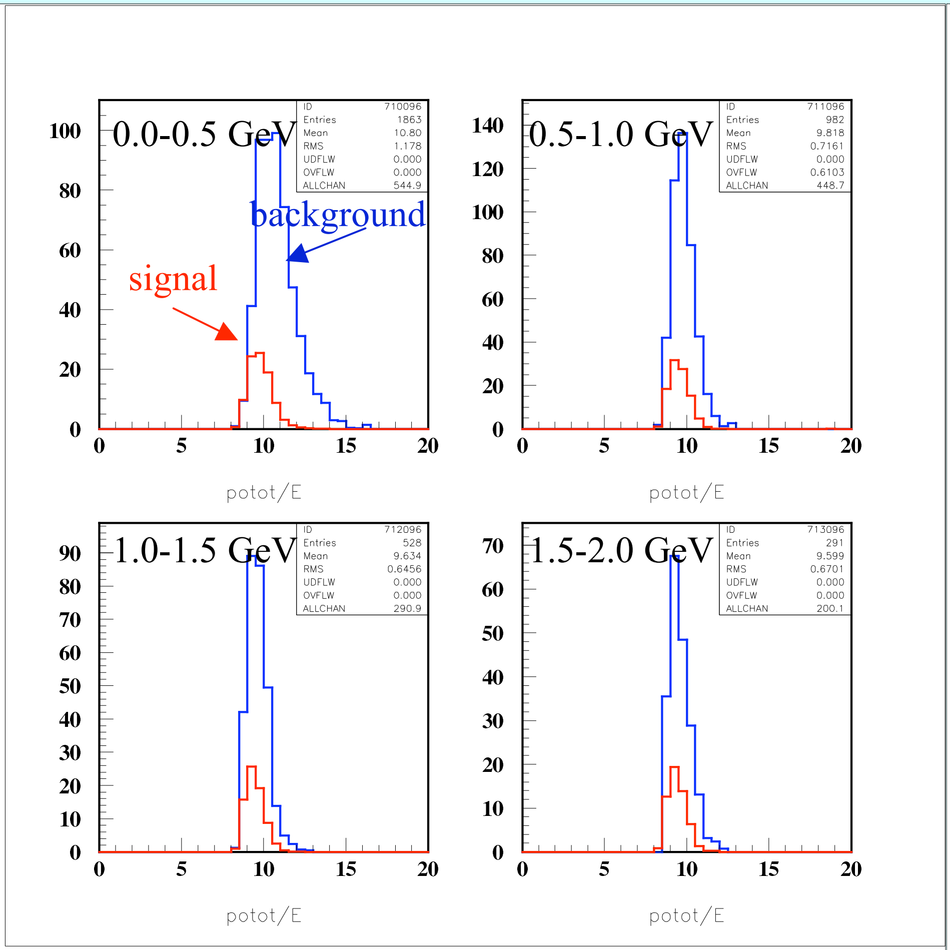


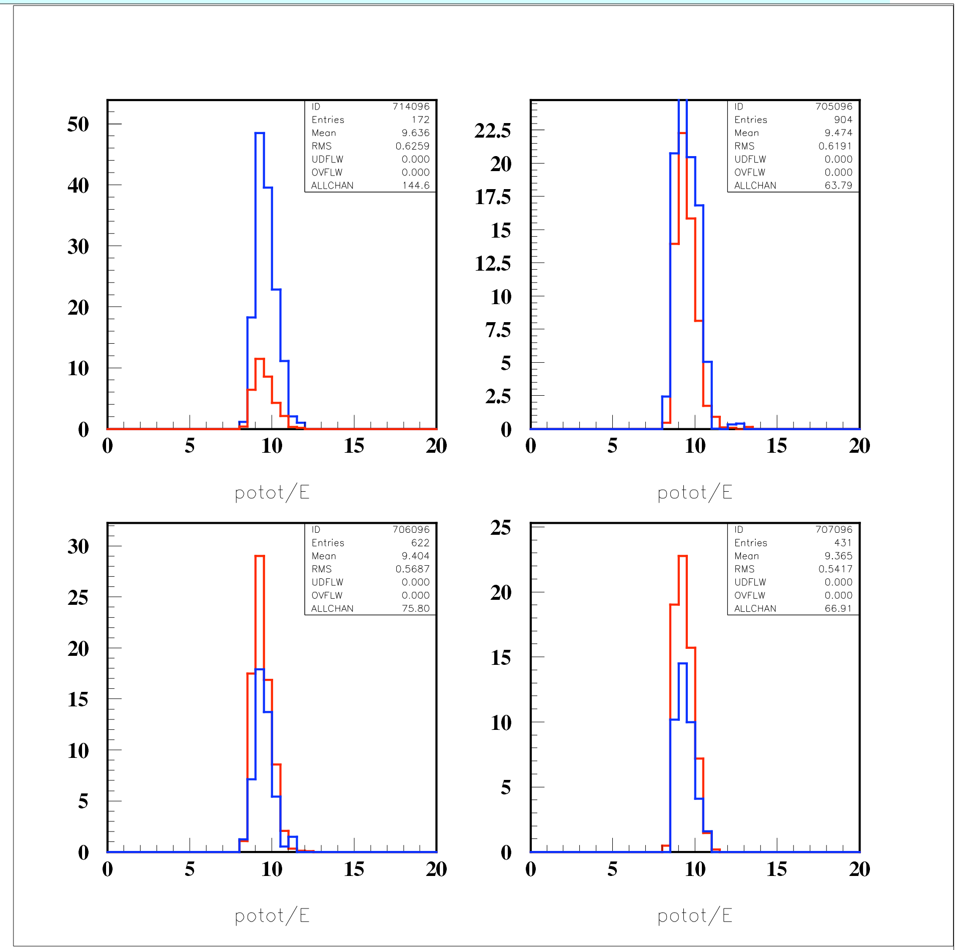
- Total charge/primary ring energy (poa)



Useful variables

- Total charge/primary ring energy (poa)



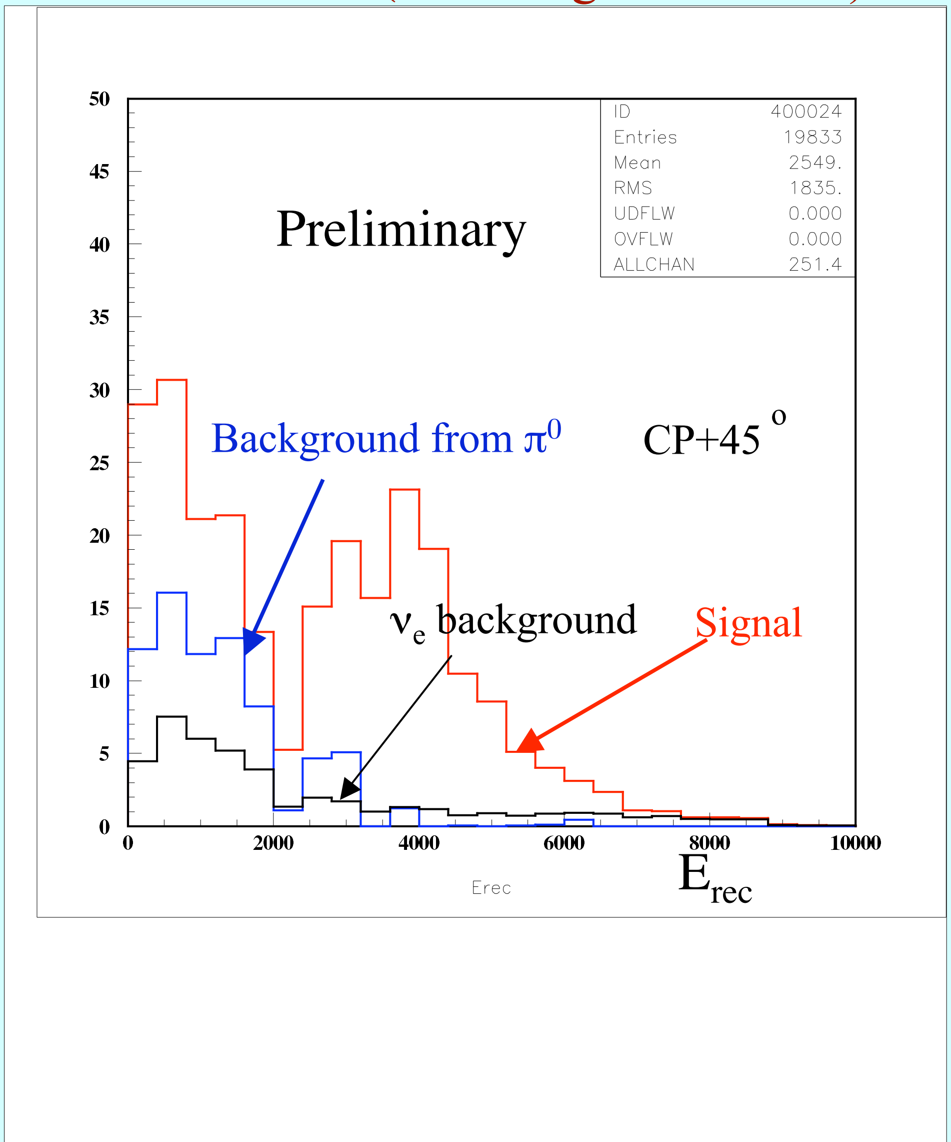


S/B

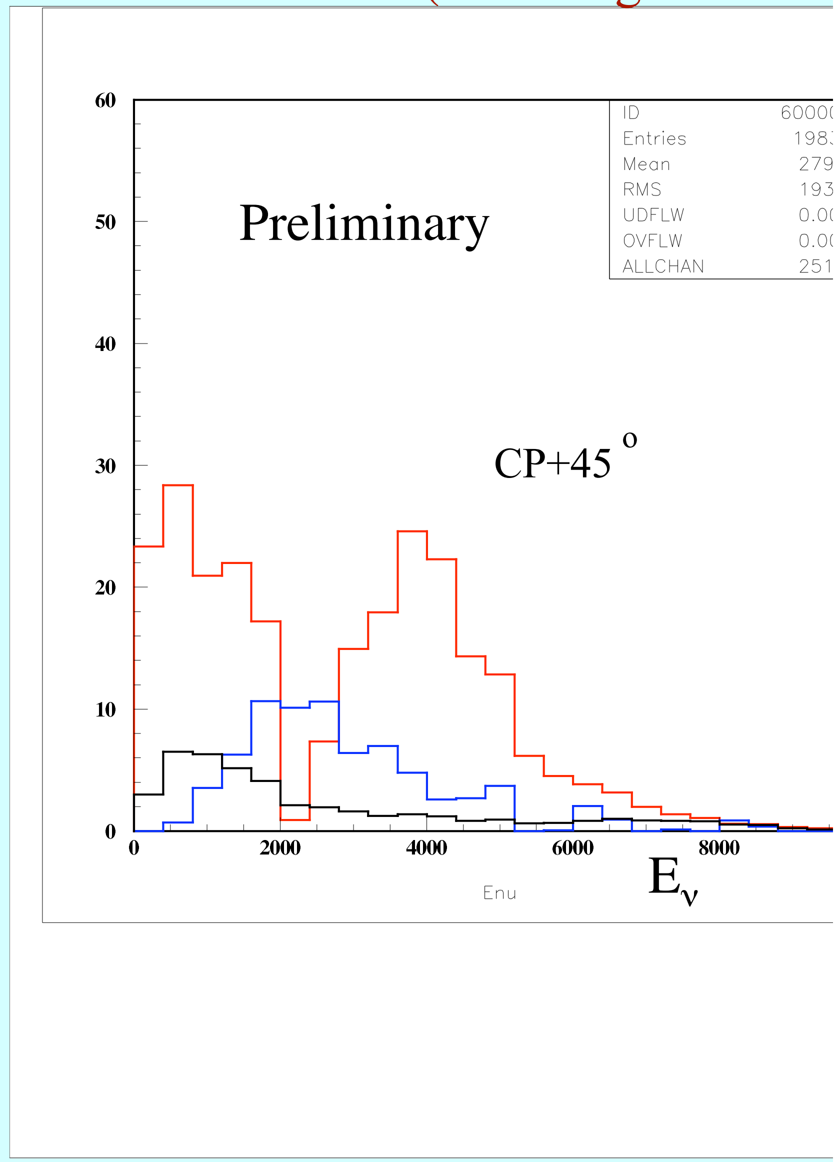
ν_e CC for signal ; all $\nu_{\mu,\tau,e}$ NC , ν_e beam for bkg

- E_{rec} vs. E_ν

Δlikelihood cut (~40% signal retained)



Δlikelihood cut (~40% signal retained)



S/B

_ Breakdown of interaction mode

Interaction mode	$0<E_{rec}<1$ GeV		$1<E_{rec}<2$ GeV		$2<E_{rec}<3$ GeV		3 GeV$<E_{rec}$	
	Sig	Bkg π^0	Sig	Bkg π^0	Sig	Bkg π^0	Sig	Bkg π
CC QE	82%	7%	69%	1%	28%	0%	50%	0%
$1\ \pi^0$	3%	3%	5%	8%	11%	0%	8%	0%
$1\ \pi^{+-}$	14%	7%	22%	1%	45%	0%	30%	0%
DIS	1%	0%	3%	1%	15%	18%	13%	0%
NC $1\ \pi^0$	0%	39%	0%	68%	0%	23%	0%	25%
$1\ \pi^{+-}$	0%	29%	0%	3%	0%	0%	0%	0%
DIS	0%	11%	0%	9%	0%	59%	0%	75%
Others	0%	3%	1%	10%	3%	0%	0%	0%

Issues

Some issues

_ S/B and variables

Neutrino oscillation was on to define template distributions
For analysis CPV=+45^o

Summary of BNL superbeam@UNO

Variable removed	Signal	Bkg	Effic	Signal	Bkg	Beam ν_e	$S/B(\pi^0)$
None	ν_e CC	ν_μ all, ν_e,ν_τ NC	50%	321	112	57	2.86
Δpi0lh	ν_e CC	ν_μ all, ν_e,ν_τ NC	50%	321	119	59	1.80
poa	ν_e CC	ν_μ all, ν_e,ν_τ NC	50%	316	126	56	2.51
pi0-lh	ν_e CC	ν_μ all, ν_e,ν_τ NC	50%	303	116	52	2.61
e-lh	ν_e CC	ν_μ all, ν_e,ν_τ NC	50%	311	127	55	2.53
efrac	ν_e CC	ν_μ all, ν_e,ν_τ NC	50%	333	167	60	1.99
pi0mass	ν_e CC	ν_μ all, ν_e,ν_τ NC	50%	310	143	56	2.17
costh	ν_e CC	ν_μ all, ν_e,ν_τ NC	50%	322	146	57	2.21
ange	ν_e CC	ν_μ all, ν_e,ν_τ NC	50%	321	119	55	2.70

Preliminary

• Future prospect/plans

- All the variables used to define the likelihood seem useful : any more?

- Some variables associated with some pattern recognition such as π^0-likelihood and e-likelihood seem quite useful

  More sophisticated pattern recognition algorithm is desirable and possible

- ν_τ CC interactions in water need to be simulated

  My first guess is that the contribution from these interactions is not large because τ is mostly produced by DIS and in general there are many particles in the event (not a single ring event).

- This kind of analysis can give an insight to optimize neutrino beam spectrum

  Studies on sensitivities to oscillation parameters should be done

  Careful study of the source of background and the associated neutrino energy is needed

  What granularity UNO needs to have?